Masters Program in **Geospatial Technologies**

VIRTUAL CAMPUS FOR THE UNIVERSITY JAUME I, CASTELLÓN, SPAIN.

3D Modeling of the Campus Buildings using CityEngine.

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VIRTUAL CAMPUS FOR THE UNIVERSITY JAUME I, CASTELLÓN, SPAIN.

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ABSTRACT

The Virtual Smart Campus for the University of Jaume I – Visca Uji – is a project that aims to transform the University of Jaume I (UJi) into a "Smart Campus". Several applications are part of the Smart Campus such as Uji Place Finder, Energy Consumption, Routes, Resources Management, and Indoor Mapping. Part of this project is the creation of the 3D model of the university buildings using Esri software — City Engine.

This study analysed two 3D modeling approaches: procedural modeling language (CGA Shape) and manual modeling. The first, Computer Generated Architecture (CGA) shape is an extension of set grammars that have been applied in CG successfully over the years. And the second, CityEngine offers a set of shape creation and editing tools that allows a more intuitive and pragmatic 3D modeling technique. Both approaches have advantages and disadvantages, overall creating a 3D model by using procedural modelling language showed to be the more efficient and pragmatic method.

KEYWORDS

Smart Campus
Smart Cities
3D GIS
Geovisualization
Computer Generated Architecture
Procedural Modeling
CGA Shape Grammar
Texturing

ACRONYMS

UJI	University Jaume I
VISCAUJI	Virtual Smart Campus for the University Jaume I
ESRI	Environmental Systems Research Institute
CAD	Computer-aided design
XML	Extensible Markup Language
GML	Geographic Markup Language
KML	Keyhole Markup Language
CGA	Computer Generated Architecture
CEJ	CityEngine Scene File
WebGL	Web-based Graphics Language

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1 INTRODUCTION

The University Jaume I (Uji) is one of the major research institution located in the Valencian Community, Spain. Created in 1991 is a public institution of higher education and research which aims for the social, economic and cultural development of the city of Castellón, in particular. UJi is a vibrant, competitive and enterprising university.

The development of a strategic plan and the formalization of their image and communication policy, endorse UJi as an entity that is committed to quality and transparent management, with a strong social commitment with its surroundings. The UJi campus, a single and attractive campus allows closer relationships between the different faculties and their students. Currently UJi has 31 degrees and diplomas courses available to about 13, 500 students, with 1120 teachers and 640 administrative services professionals.

In the last couple years, UJi decides to take an important step in their technological and economical development – the Smart Uji project. Smart UJI means Smart Campus. A Smart Campus has the goal to provide an interactive map and services that allows people to visualize, locate and access information about the campus street network, buildings, classrooms, departments, programs, offices, cafeterias, residence, green spaces, and so forth. The concept of Smart Campus follows the same principles than the known Smart Cities concept/policy: find “smart” solutions to provide quantitative and qualitative improvement of life of the populations, whether to an urban population or students in a campus.

Smart UJi intends to improve the resources and behaviour management in the campus and, most of all, aims to produce spatial data and manage information to optimize the use of all resources related to the campus. Being a university campus a smaller enclosure than a city, this concept serves real testing ground for the implementation of real Smart City.

For instance, the development of services and applications supported by a data gathering platform that integrates real time information systems and intelligent energy management systems will teach the user to learn how to interact with the building and thus, the building learns how to interact with the user in a more energy efficient way.

At this point, ViscaUJi is a map-based view of interior and/or exterior assets on the university campus that enables employees, students and visitors to locate an area of interest and review information stored in the human resources and facilities management database. In the future, will also allow employees and visitors to deliver a web-based service request or booking spaces applications and integrate other existing services like the monitoring of energy consumptions or solid wastes management. **(**GEOTEC, Geospatial Technologies Research Group, 2012**).**

Among the applications for the monitoring and management of resources currently the prototype incorporates a customer display, based on ESRI map templates, to visualize and obtain information from all of the campus outdoor spaces (sidewalks, parks, parking lots, bike routes). As well as specific elements such as trees, different types of containers residues or spots reserved for bicycle parking.

With the finalization of this project the prototype will be updated into a 3D scene. All the campus buildings, street network and all the outdoor spaces as well as, indoor spaces will be displayed in a near future in 3D, hopefully.

Nowadays, more and more people are increasingly becoming familiar with 3D visualization of the earth's surface, for instance Google Maps or/and Google Earth.

GIS applications such as ArcGIS are taking full advantage of these capabilities and empowering their software with 3D tools.

Using 3D building models is extremely helpful, such models let designers, architects, and managers virtually walk through a project to get a more intuitive perspective on their work. They can also check a design’s validity by running computer simulations of energy, lighting, acoustics, fire, and other characteristics and thereby modify or adjust designs as needed before construction begins.

In brief, this thesis will focus on the procedure of the 3D creation of the first university buildings using the new Esri software – CityEngine.

It is relevant to mention that the creation of Smart UJi and the 3D data in CityEngine is quite new and unique. There is only other example that was created in the same conditions as UJi, which is the Esri Campus in Redlands.

The following chapter reviews some relevant framework.

1.1 Theoretical Framework

1.1.1 From 2D to 3D GIS

Over the past 20 years, GIS has become a sophisticated system for maintaining and analysing spatial and thematic information on spatial objects. From paper maps to digital cartography, GIS has always been dynamic and in evolution. In the early 90's, the introduction of 2.5D concept enabled GIS to take on other dimensions and enabled users to get closer to the real world. The continuous improvements in GIS are allowing us to visualize the world in a true 3D environment. GIS is no longer 2D, but is now becoming 3D.

3D City Models are digital representations of the Earth's surface and related objects belonging to urban areas. The most common use of 3D geovisualisation today is within public planning, architecture, environmental monitoring and landscape planning. For instance, museums focus on 3D information for presentations, using its unique ability for landscape visualisation and for visualising temporal changes. Tourism plays an increasing role, while the gaming industry keeps geovisualisation under surveillance. (Nielsen, 2007)

The fact that we are now capable of building 3D City Models in a GIS environment, is allowing users to overcome some limitations of 2D GIS, such as, noise prediction models, water flood models, air pollution models, and so forth.

Many disciplines are evolving into 3D. When it comes to scientifically correct visualisations, like in geovisualisation, the advantages are many. First of all, Presentation: 3D models are natural and cognitively easier to interpret and are thus more appropriate to communicate ideas and visions; 2) Exploration: the human vision is made to quickly interpret a large amount of content or data in a scene. There are relations in a scene which the human brain perceive, often without being conscious of it; 3) Immersion: The user can be led through hardware interfaces to get the feeling of immersion into the scene and thereby to have a strong sense of being in a physical world. This has been used in adventure oriented models, as well as in product development of for instance engines; 4) Documentation: Much geographical information contains height information that are only handled as additional information in 2D; and

5) Simulations and dynamics: temporal simulations of 3D data can give new ways of studying complex processes in nature and society. (Nielsen, 2007)

The improvement of 3D data collection techniques such as aerial and close range photogrammetry, airborne or ground based laser scanning and GPS are an important factor for the development of 3D modeling.

The development of laser-scanning has reached a level sufficient for providing data for realistic 3D geovisualisation modelling, which today is the subject of various terrain models and automatic object generation.

Among the large GIS companies, ESRI has developed a series of 3D applications, the ArcGIS 3DAnalyst including ArcGlobe. ArcScene, MapInfo's Vertical Mapper is the competitive response to ArcGIS and another type of product is the CAD-related programs (Nielsen, 2007).

In CAD models such as 3D Studio Max and SketchUp, 3D objects are represented by vectors as points, lines and polygons in a coordinate system. The CAD models representations have a high degree of precision and detail therefore they are more suitable for a limited geographical area. Their use is very popular in architecture and engineering projects, and not as much for geographical projects. CAD models aren't very useful for storing associated attributes or topological information and thus are not useful for analytical tasks.

Other new techniques that push 3D GIS developments are hardware developments: processors, memory and disk space devices have become more efficient in processing large data sets, especially graphics cards also used by gaming industry.(Stoter & Zlatanova, 2003). The advancement in web technologies has greatly contributed to the successful implementation of 3D City Models to support town planning, environmental analysis, security and emergency management, as well as many other applications. (Elwannas, 2011)

1.1.2 Online Geovisualization and Standards

Today, we live in an online world. Everything and everyone is online. The web service has arrived and it is here to stay. Nowadays it is possible to image when asked about where a certain place is located to go a bookshelf and open up your world atlas? Most probably, you will use Google Maps.

Nowadays, geobrowsers such as Google maps, Google Earth, Bing maps among others revolutionary the way we see the world their ever growing popularity is due to easy access from the users and the ability to visualize large geographical areas. Online map services allow the user to visualize, interact and search for spatial information, using high quality aerial photographs.

Google Maps offers Street View that allows the user to visualize and explore places and geographical areas around the world through 360-degree street-level imagery. Bing Maps offers the Birds Eye view that allows the user to visualize the scene from above, as if the user is a bird, gaining an elevated view from the object below.

In that sense, for many years, virtual globes were mostly seen as pleasant visualisation tools, online applications that allow the user to visualize the world as it is.

However, in the last years virtual globes have been introducing 3D models. The 3D web scenes, especially of urban areas, have been developing in an impressive rhythm. For instance Google Maps offers a free modeling tool to create 3D models of any place on the globe (SketchUp Google, 2010). SketchUp is a basic, easy and intuitive program for drawing objects (buildings) and applying textures in a very automatic and practical way. Still, comparing 3D modeling tools and 3D software programs are out of the scope of this thesis.

Behind the 3D web geovisualisation, there is a language that defines a set of rules for encoding documents in a format that is both human-readable and machine. The most known is XML (Extensible Markup Language). From the large number of XML standards it is worth to mention the: Geographic Markup (GML) and the Keyhole Markup Language (KML). GML is a grammar to express geographical features and KML is a geographic notation and visualization within the web. CityGML and GoogleEarth are the most known examples.

CityGML not only represents the shape and graphical appearance of 3D buildings but specifically addresses the object semantics and the thematic properties,

taxonomies and aggregations. In the past city models often have been built as purely graphical 3D models, new applications have information needs beyond visual characteristics. Besides geometry, semantics and topology of the 3D objects have to be taken into account in order to enable for thematic queries, analysis tasks, automatic integration, validity checking, or spatial data mining.

CityGML is an open source modeling language for 3D City Models and a general information model for the representation of 3D urban objects. Berlin is an example for having an official 3D model that is based on the CityGML and uses it as the exchange format between database, editor, and presentation systems.

1.1.3 CGA and 3D Real World Representations

Real world 3D representations such as the ones presented in this study incorporate representations in a realistic way. The x, y, and z coordinates are mainly used to show the real world dimensions, elevation and/or the dimensions, including height of buildings or other objects. Additional details are suggested through photo texturing of the facades while the details are not explicitly modelled in the underlying geometric model.

There are variety of approaches based on different data sources and aiming different resolution and accuracy. Accordingly to Stoter & Zlatanova, there are four general approaches for creating 3D models:

- Bottom-up: using footprints (from existing 2D maps) and extrude the footprints with a given height using laser scan data, surveying, GPS or photogrammetry data. Consequently, this approach has the problem of the detail of roofs cannot be modelled. This approach is known to be very fast and sufficient for applications that do not need high accuracy or that don't need roofs, and many details;

- Top-down: using the roof obtained from aerial photographs, airborne laser scan data and some height information from the ground. This approach on the other hand emphasises the modeling of the roofs.

- detailed reconstructing of all details. The most common approach is to fit predefined shapes to the 3D point clouds obtained from laser scan data or 3D edges extracted from aerial photographs. The advantage of this approach is the full automation

and the major disadvantage is that it is very time-consuming since the algorithms used are very complex. And the last approach is a combination of all of them.

There isn't a general approach, the choice of the method has to take in consideration the type of project, the type of objects to model (if virtual or real), the data sources available, as well, as the software and hardware definitions.

When modelling real objects, such as in this project, the details are what makes the 3D construction/creation labour intensive. Thus, details be adjusted to the requirements of the application and the time element.

Procedural modeling, based on CGA shape grammars, is a powerful method to efficiently produce 3D building models. It offers a lightweight semantically meaningful representation instead of huge mesh files. (Mathias & Martinovic & Weissenbergy & Van Goo, 2011).

In architecture, shape grammars were successfully used for the construction and analysis of architectural design. (Bao & Schwarz &Wonka, 2013). CGA Shape has a standardized description with powerful shape operations while remaining readable to humans and a commercial tool (CityEngine) exists for rendering 3D models from CGA Shape rules. The CGA Shape grammar supports a very large number of different operations and functions in its rules.(Mathias & Martinovic & Weissenbergy & Van Goo, 2011).

Grammar-based architectural modeling has a long history. Briefly the most important facts will be exposed.

In 1971, George Stiny in his article *Shape Grammars and the Generative Specification of Painting and Sculpture* introduced the idea of shape grammars. In reality, shape grammars are similar to phrase structure grammars introduced in the discipline of linguistics. Where phrase structure grammars are defined over an alphabet of symbols and generate one-dimensional strings of symbols, shape grammars are defined over an alphabet of shapes and generate n-dimensional shapes. (Stiny & Gips, 1972).

In 2003, a breakthrough came with the introduction of split grammars in the article “Instant Architecture” by Wonka & Wimmer & Sillion & Ribarsky.

Split grammars are a specialized type of set grammar operating on shapes. Its suitability for the automatic modeling of buildings stems from the fact that restrictions

have been carefully chosen so as to strike a balance between the expressiveness of the grammar, i.e., the number of different designs it permits, and its suitability for automatic rule selection. Further development of this idea led to the introduction of CGA Shape, a shape grammar designed for the procedural generation of large scale urban models. (Wonka & Wimmer & Sillion & Ribarsky, 2003)

In 2008, Markus Lipp co-created a framework for interactive grammar editing that lead to a more approachable procedural modeling. With his article, a real-time interactive visual editing paradigm for shape grammars was introduced, allowing the creation of rule bases from scratch without text file editing. Shape-grammar based procedural techniques were successfully applied to the creation of architectural models. However, those methods are text based, and may therefore be difficult to use for artists with little computer science background. (Lipp & Wonka & Wimmer, 2008)

In summary, nowadays Shape Grammars are known for their efficiency and practical methods of creating and modeling urban landscapes. CityEngine procedural modeling language using shape grammars is a perfect example how the modeling process of an urban area can be made in a fast and expeditious way.

1.2 Motivations and Objectives

This project main goal is to create 3D data buildings for visualization, model interaction, and in further development, use the 3D data to perform simulations. As far as possible, through a virtual scene created by computer generated graphics, the model must match accurately with the real campus.

Viewing Geospatial data in 3D leads to new insights. We live in a 3D world…so model and present your data in 3D! (Sengupta, 2011)

The Visca Uji project is a very ambitious and interesting project that surely will bring more “visibility” to the University Jaume I at a national and international level. This project is all about integration. Integration of different projects that joined together will create Smart UJi. Different projects means, as well, different data sources, such as, 2D CAD files, 3D vector, Information Models, Publishing templates, UJI databases,

Satellite images, Aerial Photographs, Sensors and Crowdsourcing. This information is georreferenced, organized and prepared for further integration and publication online.

At this point, the data is published online is: ArcgGis online, ArcGis Server and ESRI topographic layer. Regarding the applications, so far the UJi Place Finder is created and operational. This is a brief description about the current status of the ViscaUJi. Further on the section “Data and Software”, the data structure will be better explained, as well as, the main properties of CityEngine.

The results of this project will be 3D university buildings that will be used as a shell to visualize and interact with other applications, for instance, indoor mapping navigation and/or energy consumption. Additional benefits of using 3D models for simulations, provides a better platform for generating realistic renderings of new infrastructure, especially if a temporal context, such as solar or seasonal studies, is required. 3D city models are also used for security applications such as landslide prevention or flood simulation.

Using the base information from Uji (Uji database), it will be possible to produce 3D content with a distinctive conceptual design and modeling solution for the efficient creation of 3D university buildings, streets and exterior spaces (such as trees, urban furniture and so forth). In addition to the 3D models visualization and user interaction, this project will produce data – 3D data. That hopefully will be displayed and used as platform for other applications.

2 METHODOLOGY

The methodological approach used in this project is summarized in Fig. 1 and described in this section. The dashed lines represent future work.

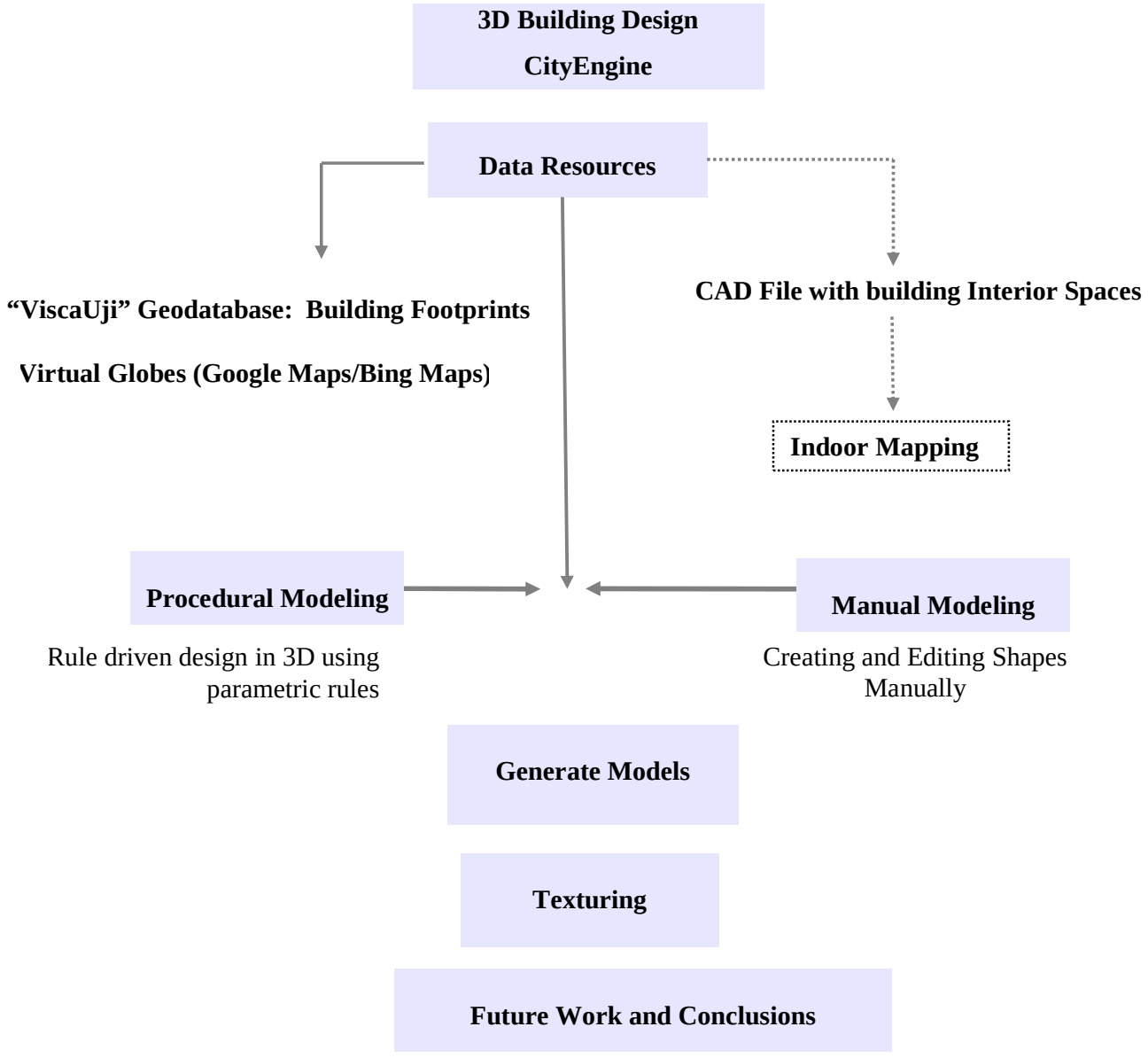


Figure 1: Flowchart of the methodology used in this study.

The workflow for this project starts with the design of the 3D buildings in CityEngine. From the moment CityEngine is installed, its learning process begins. It is important to understand what CityEngine main strength is and what makes it different. Many materials, tutorials and demos are available on the web and were crucial for learning how to work with CityEngine.

The next step was the integration of the data resources available for this project. In the Figure 1, virtual globes are mentioned not as data source, but as online tools that allow a better perspective of a building. The use of Google Maps, Google Earth and Bing Maps revealed to be very useful since it allowed the visualization of the university buildings without having to travel to the campus every other day. However, Google Maps and/or Google Earth don’t have access to all the streets in the campus. The simple going around a building was in some cases impossible. On the other hand, Bing Maps became a good resource, especially with the Bird's Eye view. The elevated view of the buildings from above gave a good perspective that Google Maps in some cases, couldn't. On section 2.2 the data resources will be explained with more detail.

After importing and integrate the source data into CityEngine, the practical creation of the 3D buildings begin. There are two main methods for the creation of 3D data: manual modeling and procedural modeling. The main goal is to experiment both methods, describe them and in the end, compare them. For the procedural modeling method the university buildings ESTCE, Student's Residence, Workshops and Ágora were created. And for the manual modeling the chosen buildings were the sports pavilion and auditorium building. From section 2.3 till section 2.6, a detailed description of the methods is presented, as well, the explanation of both procedures applied for each building mentioned previously.

Texturing the model is the last process of the buildings 3D model creation and consists of assigning digital or photograph textures to the buildings.

Finally, on the final sections of the document an analysis will be made regarding the both methods, the performance of the software, its main advantages and disadvantages, as well as, the main contribute of this study.

2.1 The Campus

The Uji Campus modeling process includes the design and drawing of the model in 3D, visualization and adding realism to the made models by applying real facades.

Figure 2: Campus area in CityEngine with the finalized 3D buildings.

The Uji campus is a quite large and ample campus, for that reason and regarding the deadline factor, is wasn't possible to model all the buildings in 3D.

The buildings created in 3D were somehow randomly selected. Some reasons such as, complexity of the building design, facades patterns, and the strategic importance of the building in the campus were factors on my mind. The buildings modelled in CityEngine were: the School for Technology and Experimental Sciences (ESTCE); the Students Residence; the Ágora buildings; the Workshop building; the Sports centre; and the Auditorium building.

Figure 2 illustrates a final version of the Uji campus in CityEngine.

2.2 Software and Data

Esri CityEngine is a 3D modeling software application developed by Esri R&D Center Zurich (formerly Procedural Inc.). CityEngine was best known for their use of procedural modeling approach in the creation of urban scenarios for video games and movies. CityEngine creates urban environments from scratch, based on a hierarchical set of comprehensible rules that can be extended depending on the user's needs. (Muller & Parish, 2001). This approach enables the efficient creation of detailed large-scale 3D city models, in a less time-consuming period.

Esri CityEngine main advantage is the capability of modeling a complete urban landscape using a comparatively small set of statistical and geographical input data. Specifically for this project, the 2D campus building footprints were the only data needed to simply apply an extrusion operation and apply the rules for the creation of the 3D buildings.

In my opinion, CityEngine is an attempt to unify three major areas: GIS/Geography, Civil Engineering and Computer Graphics/Design. This means that, CityEngine was created to combine GIS with computer generated architecture. CityEngine allows the compilation, use, and manage of geographic information, including shapefile and file Geodatabase format (ArcGis native formats). As well as, performing many GIS tasks, such as: mapping, data compilation, analysis, Geodatabase management, and geographic information sharing (Web/Online).

The ability to easily create 3D urban scenes based on existing GIS data is one of the key strengths of CityEngine. The software allows you to create high-quality 3D content using nothing more than a combination of 2D data, attributes, and procedurally defined rules. This means that any GIS organization will be able to create visually stunning 3D urban environments using the data they already have. (Muller & Parish, 2001)

The data used for the model creation was organised in a Geodatabase that follow ESRI model known as Local Government Information Model, a schema-only layer package containing the schema of the data it references. The content schema was migrated into a geodatabase design

This allowed benefiting from a structure of predefined relationships between the different elements that characterize infrastructure and services, just like a city government.

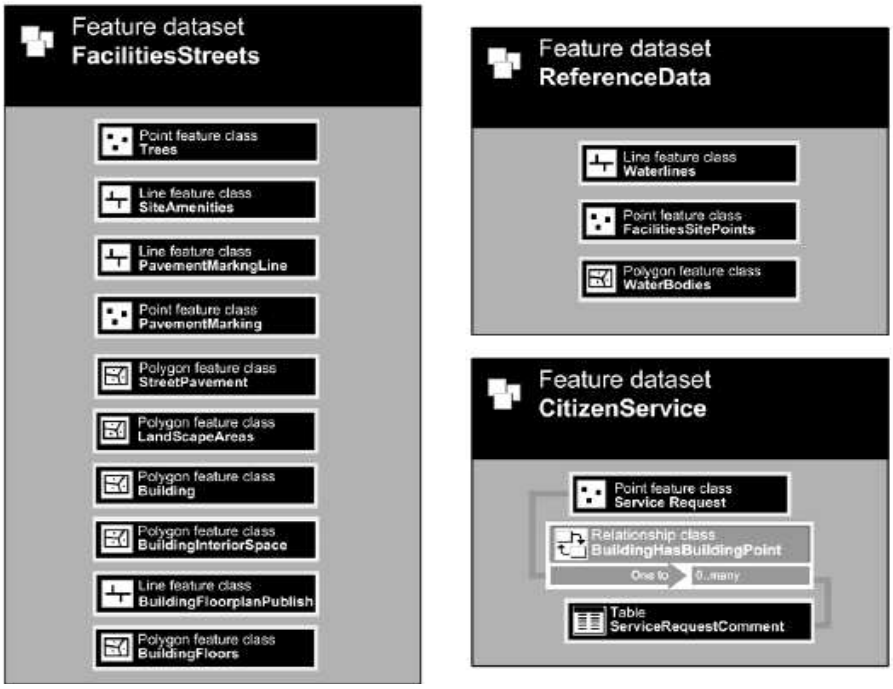


Figure 3: Esri Local Government Information Model applied to ViscaUJi project (Sanchis & Arnal & Molina & Sanchis & Díaz & Huerta & Gould, 2012).

This geodatabase was the main data source we had access before starting the realization of the project. Apart from that, there were CAD files of some of the buildings that included interior spaces lines; and an Excel database of some of the UJi buildings. The database fields were about the physical characteristics of each space, such as, surface area, building name, floor number, floor ID, space ID, which is the unique identifier of each indoor space. This identifier can be related to other data such as the faculty, department, use, staff and their contact information, equipment, facilities use, energy consumption, and so on.

After having access to the data, the geodatabase was imported into CityEngine. There were some initial problems regarding the reference system when loading it, since the file geodatabase had to be in WGS 1984 World Mercator, the same reference system in ArcGIS.

CityEngine's file system can be seen on the figure3. The data structure is organized in folders and it is arranged in the Navigator window.

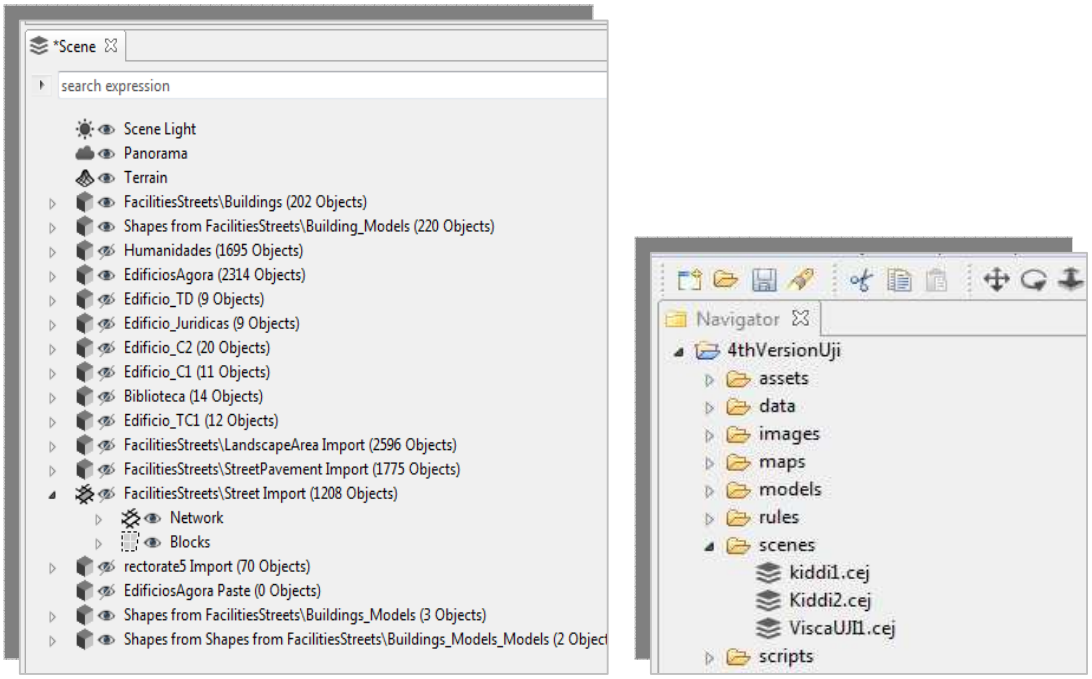


Figure 4: CityEngine ViscaUji File System. On the left image, the Scene view and on the right image the Navigator view.

The Navigator is the main tool to navigate and operate on files and folders. It is possible to edit CGA and scene files as well as providing the basic operations such as copying, renaming and deleting files and folders.

Bellow the Navigator window, is the Scene. The Scene window is the central place where you manage the scene and where the data is displayed in layers, a bit similar to the ArcGis Table of Contents. Currently, the following layer types exist: environment layers control such as scene's panorama or the scene light; graph layers containing street networks and blocks; dynamic shapes (street shapes, building footprints), and generated models. Shape Layers contain static shapes, typically used as building footprints for generation of CGA models. (CityEngine, Guide, 2012). The format of the scene files are CEJ.

Next on the Figure 4 is a view of the CGA rule editor. The CGA rule editor allows the user to write, modify, add and replace rule files. It is an interactive window for the user to work on their rule files. Since CityEngine main strength is working with procedural modeling language and the creation of CGA rule files to generate models, this window is essential.

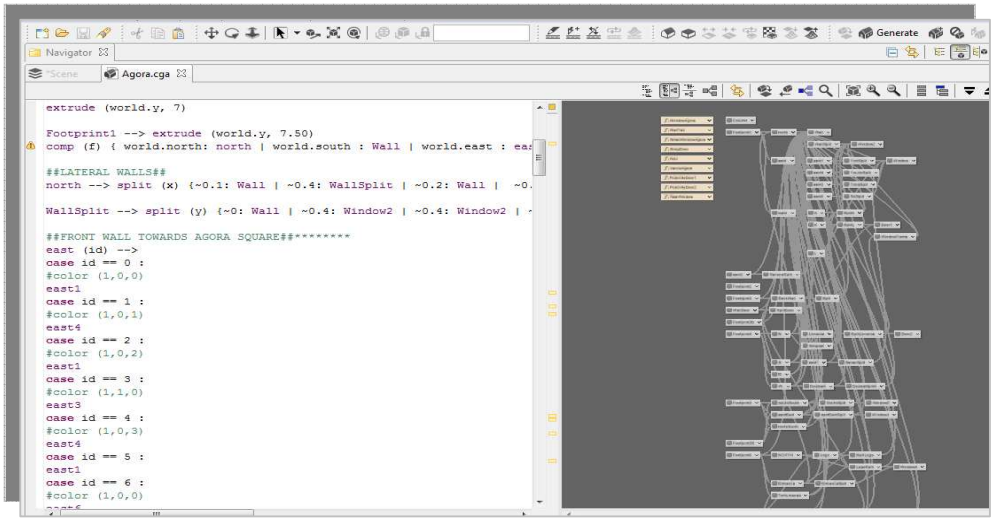


Figure 5: View of the CGA rule file in the CGA rule editor window and on the right, the schematic view of the rule.

Following the CGA Editor View, the "Inspector" allows the user to visualize and modify CityEngine objects. Depending on the type of object selected – shape, face, edge or vertex – the inspector provides full access to the object's attributes, materials, vertices and information. Users that are familiar with ArcGIS family of software, this window is more or less similar to the Attribute table. Although, the appearance it is not a table, the list of attributes is exposed and the user is free to modify, add and/or delete attributes.

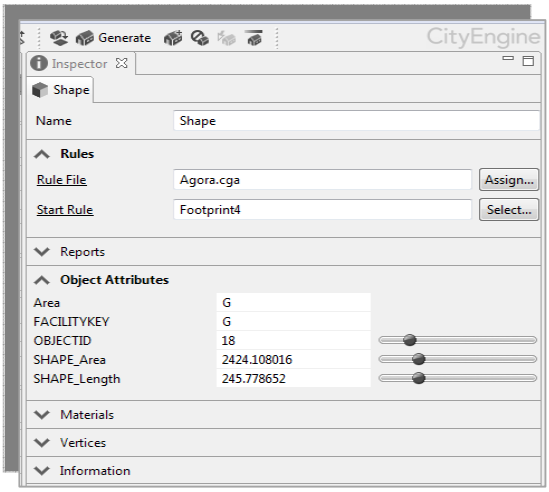


Figure 6: The Inspector Window for the Ágora CGA rule file.

2.3 Production Process

After describing the software main properties and specifications, and the data resources, this section will explain how the creation and design of the 3D models processes.

Usually, the 3D model creation starts by designing the street network. However, since this is a shared project, the 3D buildings are what this study will focus. Later, this will have some implications when joining of the data.

The design of the 3D models always starts by extruding the buildings. A complete 3D building model has three major assemblies: walls, architectural components, and floors and ceilings. Extrusion should handle each assembly differently according to its unique characteristics and the specific application needs. (Muller & Parish, 2006)

Extrusion operation is applied to the building footprints, from thematic 2D map, using CGA rules and according to their approximate height. All heights of the buildings were calculated by floor (each floor on average has 3 meters). The attribute height is always possible to change using the procedural modeling language, meaning that it is possible to change whenever.

Due to the nature of the CGA Shape, this ensures that the resulting rule set is size-independent and can later be used in a flexible way. (Muller & Parish, 2006)

Each building in Uji is complex and composed by different and multi geometries. In some cases, the buildings have different types of textures or colours in their facades.

During my learning process of CityEngine, it was decided to apply a rule per building. Somehow, this goes against the main "power" of this software, since City Engine's strength relies on generating city landscapes using one CGA rule file. However, a single rule file was applied for each building, since each building at UJi is unique, from an architectural perspective. CityEngine is use best for huge masses of buildings which obey the same rules; it is not really the best tool to recreate individual real world buildings. (Matthias Buehler, ESRI Senior)

2.4 Procedural Modeling

Procedural modeling language can simply be defined as a programming language that uses algorithms/ rules – CGA shape grammar rules. CGA shape, a novel shape grammar for the procedural modeling of CG architecture, produces building shells with high visual quality and geometric detail. (Muller & Parish& Haegler & Ulmer &Van Gool, 2006)

The CGA shape grammar is defined by four components: a finite set of shapes; a finite set of attributes; a finite set of operations; and a finite set of production rules.

A shape consists of a symbol (string), geometry (geometric attributes) and numeric attributes. Shapes are identified by symbols, usually a string.

Geometric attributes correspond to the scope, an oriented bounding box in space (Figure 6). The most important geometric attributes are the position P, three orthogonal vectors X, Y, and Z, describing a coordinate system, and a size vector S. These attributes define an oriented bounding box in space called scope. (Muller & Parish& Haegler & Ulmer &Van Gool, 2006)

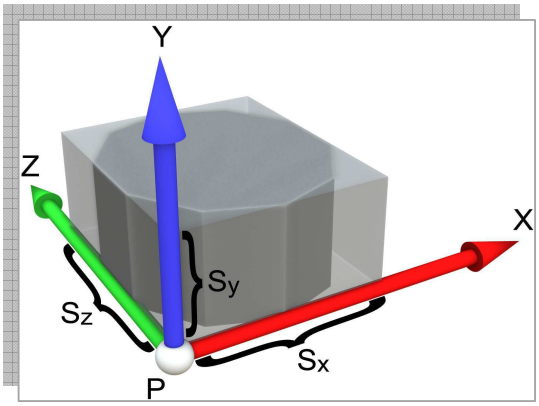


Figure 7: The scope of a shape. The point P, together with the three axis X, Y, and Z and a size S define a box in space that contains the shape (Muller & Parish& Haegler & Ulmer &Van Gool, 2006).

Shape Operations are a very important component in the shape grammar and there are essentially four types. First, the Scope operations modify the scope of a given shape and include translation, rotation, and resizing. The Split operations split the scope along a given axis, with split sizes as attributes. The Repeat operations repeat a shape in a given direction as long as there is enough space. In CGA Shape they are written as a part of a split rule. For example, a window gets repeated over the whole length of a floor. And lastly, the Component split operation splits 3D scopes into shapes of lesser dimension, e.g. faces, edges, or vertices. (Mathias & Martinovic & Weissenbergy & Van Goo, 2011).

Shape grammar rules modify and replace shapes. Iteratively evolve and develops a design by adding more and more details (wall, floors, windows, doors). The model production usually starts from an initial shape, which is most commonly a building footprint. This shape is gradually refined as rules are successively applied.

In summary, the example of the shape grammar is a tree-like structure. Its nodes represent shapes, split, component split and repeat operations, capturing the structure of the building. The process begins with the extraction of shape symbols, and their classification as terminal or non-terminal shape symbols. In the next step, the rule set is analyzed, creating the tree structure.

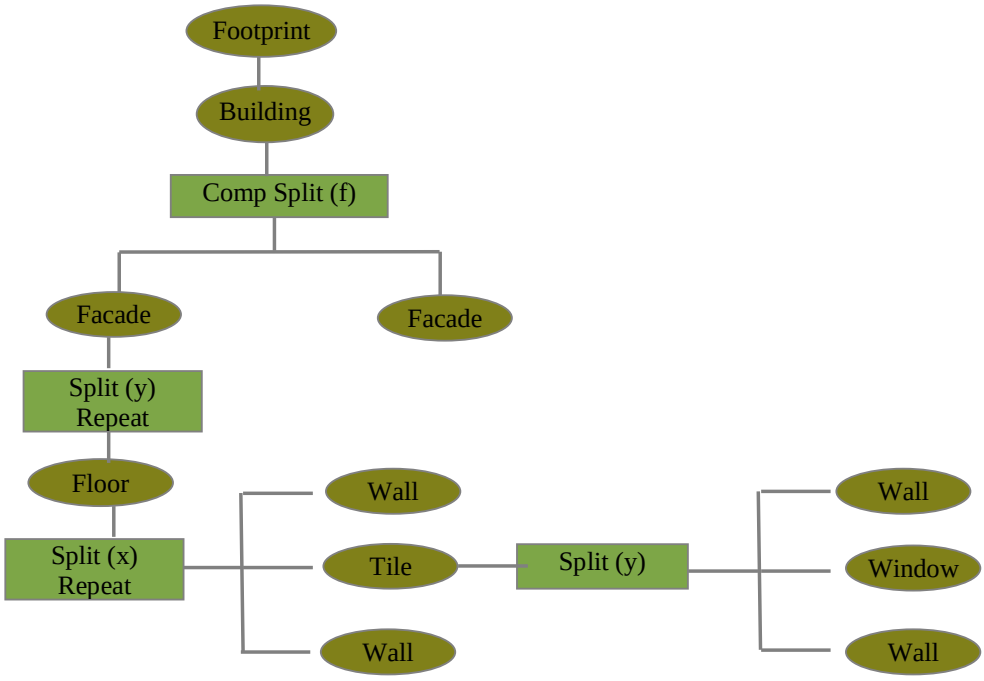


Figure 8: CGA rule like shape tree.

In the following section, the design process will start by applying CGA shape grammar rule to some buildings on the campus. Further concepts and specifications will be described.

2.4.1 ESTCE Building

The first building campus modelled in 3D was the *Escuela Superior de Tecnologías y Ciencias Experimentales* (ESTCE). This building is where the GeoTech Master department is located. The geometry of the building isn't very complex.

Figure 9: ESTCE building located on the southwest corner of the Campus. (Departament de Matemàtiques. ESTCE. Universitat Jaume I, January 2013. http://www.deptmat.uji.es/).

Figure 10: CityEngine Web Scene 3D Model of the ESTCE building.

When modeling a real building it is important to first look at the geometric shapes of the building, as well as, the building height, the facades (if they are identical or diverse, type of windows, types of textures, etc.). Building mass models are most naturally constructed as a union of volumetric shapes (Le Corbusier 1985; Mitchell 1990).

It is important to have a clear idea of what is going to be modelled. To help in that task taking photographs *in situ*, and in case it isn't possible, using online virtual globes such as, Google Maps, Bing Maps and Google Earth is essential to get the whole picture of the building.

In order to make easier the process of modeling the building, the building footprint is divided into four shapes. To all of them a different rule is assigned.

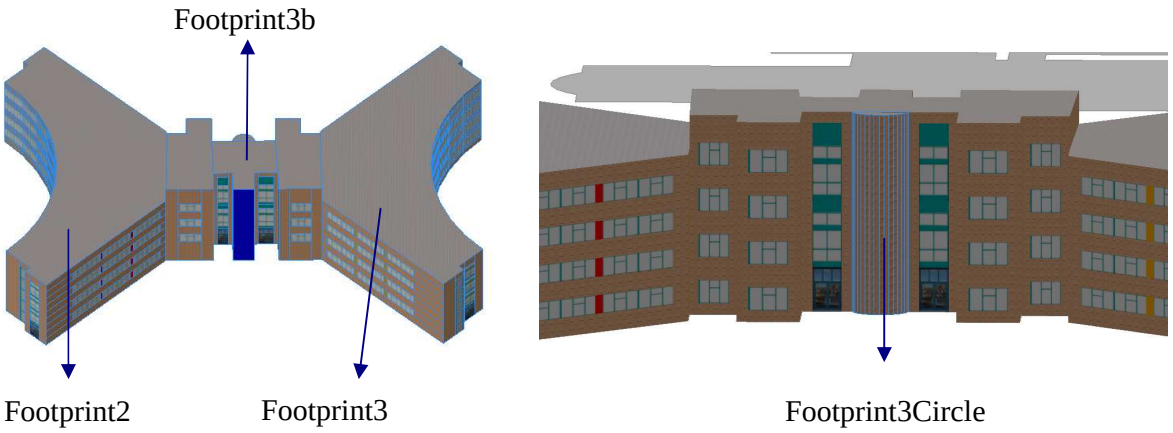


Figure 11: Image on the left: Wireframe on shaded/textured view of the 3D building and subdivision of the footprint. Image on the right: Back side of the building.

The first and basic operation to generate a 3D building is called **Extrusion** (Line 1 of the code). This operation will increase the three-dimension of the footprint according to the height value of the building its defined. The three-dimension has to be aligned correctly with the up axis in the world coordinate system, in this case the WGS 1984 World Mercator. Usually it is defined on the rule file as "StartRule". It is important to define it; otherwise the rule won't be assigned.

```
1: Footprint1 --> extrude (world.y, 20)
```

Next, the **comp** operation is applied (Line 2 of the code). The **comp** operation splits the mass model into faces, edges or vertices. The components can be selected using either their *index* or a set of semantic selection

keywords. The selected components are transformed to a new shape and processed by a sequence of shape operations.

```
2: comp (f) {object.front: EastFacade. | object.back: SouthFacade
(comp.index) | object.left: SouthEastFacade1. | object.right:
WestFacade (comp.index)| object.top: Roof }
```

Usually, the comp operation is used first to split the mass model into facades, in this case using the selectors: object.front; object.back; object.right;object.left; and object.top. In further rules different selectors will be used, such as, world.north, world.south, worl.east and world.west.

The names given to the facades are completely random and dependent on the user decision. At some point, it became difficult to choose which expression to give to the new shapes since they are so many.

The “SouthFacade” had to be split again using the **comp.index** operation. This will happen in other occasions throughout the designing process. Probably, due to the drawing of the building footprint originates discontinued facades. Figure 10 illustrates the “SouthFacade” with discontinued facades. And next the respective rule used to solve this issue.

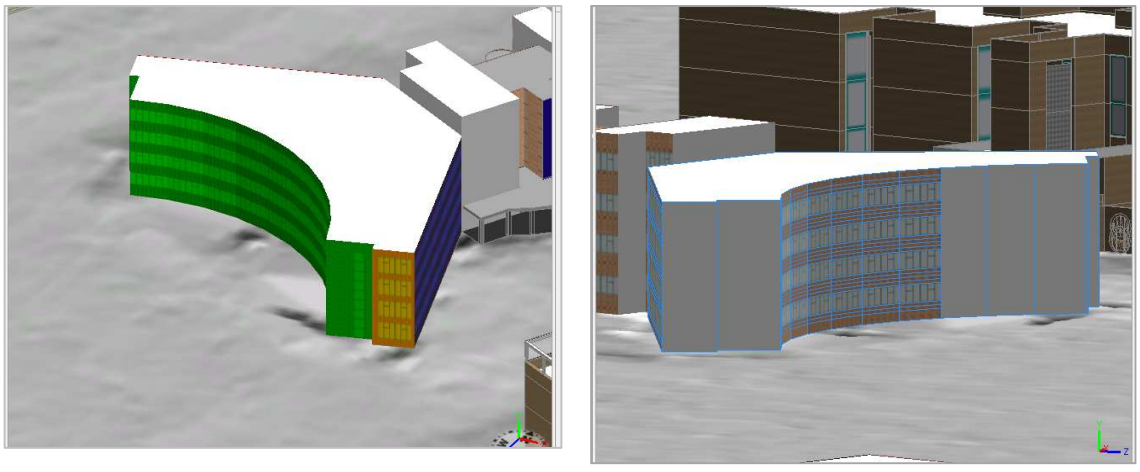


Figure 12: On the right, the output of the “Comp.index”o peration. The left image shows discontinued facade.

```
3: SouthFacade(id) -->
4: case id == 0
5: color (1,0,0)
6: SouthEastFacade1.
7: case id == 1 :
8: color (1,0,0)
9: texture
10: case id == 11 :
11: color (1,0,0)
12: Shape11.
13: case id == 12 :
14: color (1,0,0)
15: ShapeLateralWindow2.
16: case id == 13 :
17: color (1,0,0)
18: texture
19:  else:
20:  SouthFacadeComplete.
```

The **comp.index** is a zero-based index that assigns an index to each shape that composes the facade. This operation allows the user to subdivide the facades in many shapes as possible and work on them individually. The “color” operation was used to identify the right facade while working on it.

Once the facades are correctly split, it is possible to apply textures whether is a simple wall or a facade with floors and then windows. Either way, it is important to specify in the code the correct path of the textures to be used. Usually, all the texture files (jpg., png., etc.) are located on the folders images and/or assets. This location isn't mandatory. In the CGA rule file, the textures are usually written in the beginning of the code.

```
TEXTURES

MainTexture = "assets/facades_uji/ladrillo_caravista_det.png"
WindowTexture = "assets/facades_uji/VENHO_TI.jpg"
MidTileTextureRed = "assets/facades_uji/GRANATE MATE.jpg"
SideWindowTexture = "assets/facades_uji/VENHOC_TI_cropped.jpg"
LateralWindowTexture ="assets/facades_uji/VEN.jpg"
UjiBlueTexture = "assets/facades_uji/MORADO UJI.jpg"
GreenTileTex = "assets/facades_uji/VERDE UJI.jpg"
DoorESTCE = "images/DoorESTCE.jpg"
```

Usually in the beginning of the design process, the textures for the wall, windows and doors are the first rules to be created. This will be important since when applying the rules for creating floors, windows and doors, the textures are already created. Below, on lines 10 to 18 the rule for the wall texture and the window is created.

```
10:   Walltexture -->
11:   setupProjection(0, world.xy, 1.5, 1, 1.5)
12:   texture(MainTexture)
13:   TileUV(0, ~1, ~1)
14:   projectUV(0)

15:   window -->
16:   setupProjection(0,scope.xy,scope.sx,scope.sy)
17:   texture(WindowTexture)
18:   projectUV(0)
```

To apply and perfectly display a specific texture in a facade, a window or any other architectural element, it is essential to understand at least six types of operations: setupProjection, projectUV, translateUV, scaleUV, tileUV, roatateUV.

The setupProjection operation initializes a projection matrix for the chosen uv-set based on the reference coordinates system specified with axesSelector. It can be chosen between scope and world coordinate systems. (CityEngine Help, 2011) Both were used in many rules, the parameters change but the output is the same.

The projectUV operation creates the final texture coordinates of the selected uv-set by applying the corresponding projection matrix. Thus, this operation 'bakes' the texture projection into the texture coordinates of the geometry of the current shape. The projection is based on the uvw-coordinate system specified by the setupProjection operation. (CityEngine Help, 2011)

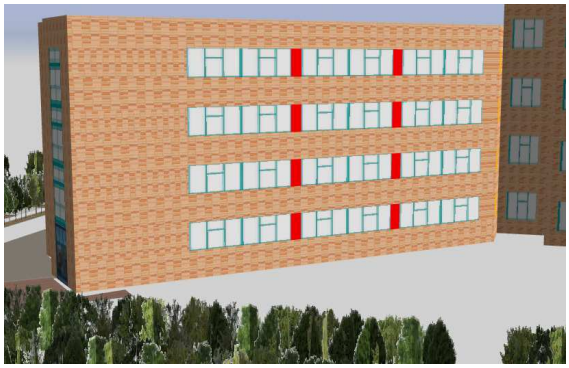
The tileUV operation rescales the texture coordinates of the selected uv-set such that the uv space gets tiled with tiles of a given width and height (the last two parameters on the parenthesis). The textureWidth and textureHeight parameters support usage of the floating and relative operators to avoid complex calculations with the texture space dimension. (CityEngine Help, 2011)

Continuing with the design of the Footprint1, the east-orientated facade is a very good example of how to divide the facade into floors, windows and applying the textures.

Next on lines number 1 till number 7 are the two split rules. When assigned to the facade, it will split it into floors and windows and in this case in particular, with red column between each window.

The most common subdivision scheme used was:

- Facade > Floor > Wall > Window > Door



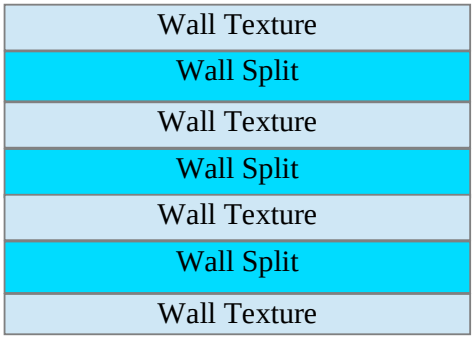


Figure 13: On the right, CityEngine Web Scene detailed view of ESTCE's South Facade. On the left, a Split Operation along the Y axis on a basic facade design.

The generic expression for a XYZ Split (Cartesian Space) is: split(splitAxis) {size1: operations1 | size2 :operations2 | ... }.

```
1:    EastFacade. -->
2:     split(y) { ~1:  Walltexture | ~1: wallSplit | ~1: Walltexture |
3:    ~1: wallSplit| ~1: Walltexture | ~1: wallSplit| ~1: Walltexture |
4:    ~1:wallSplit | ~1: Walltexture}

5:    wallSplit -->
6:    split(x) {~1: Walltexture | ~1: window | 1: column | ~1: window
7:    |1: column | ~1: window | 2: Walltexture }


8:    column -->
9:    color ("#ff0000")
```

The Split operation is in my point of view one of the most important operations in procedural modeling. It is quite important to fully understand it since, from the moment it is understood; it is possible to design almost every building.

The split operation subdivides the current facade along the specified scope axis (X, Y, Z) into a set of smaller shapes, as many as desirable.

The name of the shapes: Wall Texture (rule that defines as wall texture the light-brown bricks) and Wall Split (the shape that will receive the windows).

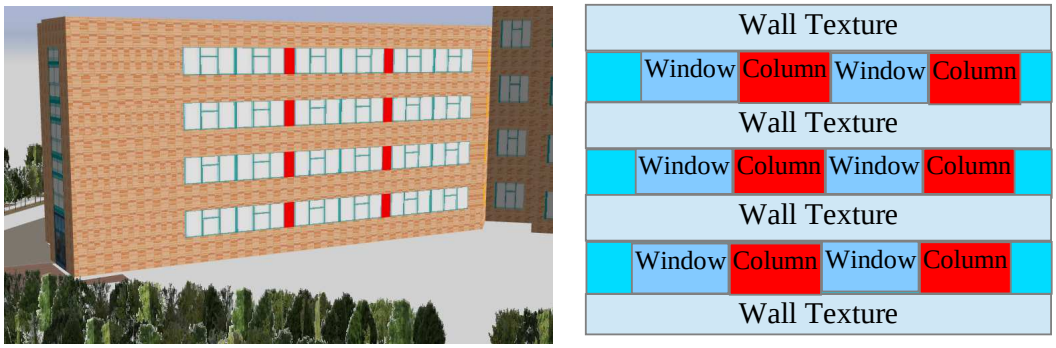


Figure 14: On the right, CityEngine Web Scene detailed view of ESTCE's South Facade. The image on the left is the Split Operation along the X axis, in a basic facade design.

The “WallSplit” rule (line 5 to 7) splits the shapes along the Y axis, again as many times as desirable. This is called “The Parallel Repeat Split”.

At some point, depending on the direction of the facade, it was possible to visualize some distortion of the wall and window textures. These problems were solved by changing the parameters on the texturing operations, previously explained.

The ESTCE building entire code is on the appendices (Annex 1) for further analysis. Hopefully, the most important part of the design and creation of this building were clearly exposed. The others footprints follow the same designing process.

2.4.2 The Students Residence Building

The student's residence building is the second one to be modelled in 3D using procedural modeling language. In reality, this building was one of the hardest to create, since it has architectural components such as columns, railings and facades with different colours. Figure 13 shows photographs of the building. And on figure 14 the 3D model of the building.

Figure 15: On the left North West view of the Residence. (tuestudios.com. Residencia Universitaria Campus – Castellón. January 2013. http://www.tusestudios.com/content/residencia-universitaria-campus-castellon-2). On the right image: South view of the Residence. (Jiménez, Olivia. *oidocozina.blogspot.com.es.* May2012.January2013. http://oidocozina.blogspot.com.es/2012/05/independencia-universitaria.html)

Figure 16 : CityEngine Web Scane 3D model representation of the North West and South facades of the Student's Residence Building.

For the Student's Residence the same design approach was taken. The complete CGA rule is on the annexes (Annex 2). However is worthy to explain some operations that made this building different.

Firstly, on the upper image in figure 14, is possible to visualize columns and a two facades have a certain pattern of colours.

The design of the columns footprint was created with ArcMap, using the building footprint. So far, CityEngine doesn't supply tools to create circles, only polygons and rectangles. Once the columns footprint was created, it was imported into CityEngine and by applying a simple extrusion operation, the columns were created.

Next, the facade with the colour pattern was created. Above, the code on lines 4 and 5 create the first floor were the columns were designed. Since they overlay the building - “footprint1aa” - the NIL operation was used.

The NIL operation basically creates holes. Since the columns were on top of the building footprint and to avoid the overlaying, the first floor, which in reality it isn't the first floor, has to be NIL.

The following floors are split accordingly to the colour segments of the real building (lines 4 to 14). Note that specifically for these facades, the floor split operation was done along the Z axis.

```
1:  Footprint1aa --> extrude(world.y, 24)
2:   split (y) {~1:   FirstFloor| ~1: SecondFloor | ~1: ThirdFloor |
3:  ~1: FourthFloor | 2: FifthFloor }

4:  FirstFloor -->
5:  split (z) {~1: NIL | ~1: NIL | ~1: NIL }
6:  SecondFloor -->
7:   split(z) { ~1: pinkWindowSegment | ~1: yellowWindowSegment | ~1:
8:    yellowWindowSegment }
9:  ThirdFloor -->
10:   split(z) { ~1: yellowWindowSegment | ~1: yellowWindowSegment |
      ~1: pinkWindowSegment }
11:  FourthFloor -->
12:   split(z) { ~1: yellowWindowSegment | ~1: pinkWindowSegment | ~1:
      pinkWindowSegment }
13:  FifthFloor -->
14:    split (z) {~1: yellowRoofSegment | ~1: yellowRoofSegment | ~1:
      pinkRoofSegment }

15:  pinkWindowSegment -->
16:  split(y) {~1: color("#ff9999") X | 2: windowTex}
17:  yellowWindowSegment -->
18:  split(y) {~1: color("#ffff66") X | 2: windowTex}
19:   yellowRoofSegment --> comp (f){top: color ("#b7b7b7") X | side:
20:  color("#ffff66") X}
21:  pinkRoofSegment --> comp (f) {top: color ("#b7b7b7") X | side: 22:
color("#ff9999") X}
```

In the West facade of the building, an identical situation happened with the ground floor. Figure 15 illustrates that issue.

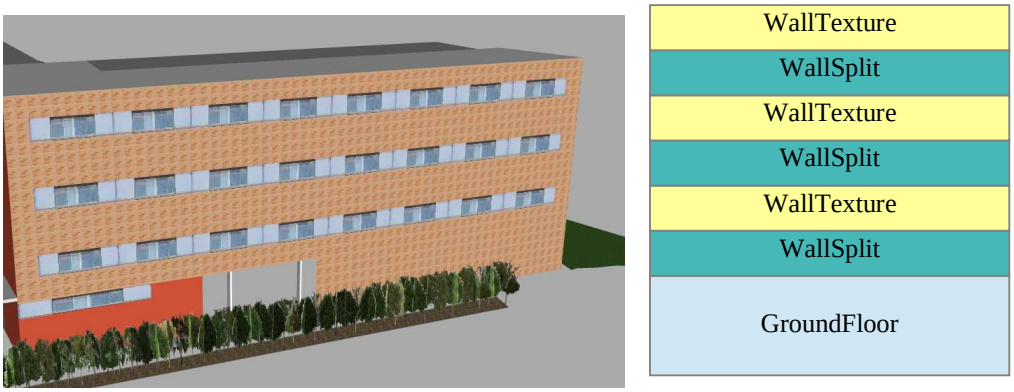


Figure 17: On the left image: CityEngine Web Scene view of the West facade 3D Model. On the right, SideFacade Rule, split along the y axis on a basic facade design.

```
1:      SideFacade -->
2:      split(y) {~2: GroundFloor | ~0.5: wallSplit| ~1: Walltexture
3:      |~0.5: wallSplit| ~1: Wall2 | ~0.5: wallSplit | ~0.5:
4:      Walltexture}

5:wallSplit -->
6:      split(x) { 2: Walltexture | ~ 1: windowTex |  ~1: windowTex |
7:      ~1:   windowTex | ~1: windowTex | ~1: windowTex | ~1: windowTex
8:      | ~1:       windowTex | ~1: windowTex | 2: Walltexture }
```

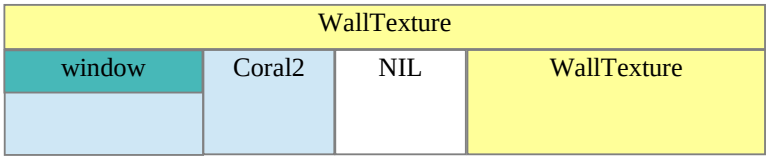


Figure 18: Ground Floor rule on a basic facade design.

```
9:      GroundFloor --> split (y) {~4: F | ~1.5: Walltexture }
10:     F --> split (x) {12: C| 5: Coral2   | 12: NIL | 32: Wall2}
11:     C --> split (y) {~3: Coral2 | ~1: windowTex}
```

In this building real photographs of the windows were taken “in-situ” and applied in the facade. Further, in the section “Texturing the model” it will be explained how this procedure works and the best-practices.

Lastly, the design of the railings was created by using the following code:

```
1: Extra →
2:  s('1, '1, 0.3)
3:  i("builtin:cube")

4:  Railing →
5:  [t(0,scope.sy-barDiameter/1,0) HBar ]
6:  set(trim.vertical, false)
7:  split(x){ 3 :  VBar }*

8:    VBar --> s(barDiameter,'0,barDiameter) t(0,0,-barDiameter)
9:    i(cyl_v) color("#6E6A6B")
10:  HBar --> s('1,barDiameter,barDiameter) t(0,0,-barDiameter) i(cyl_h)
11:   color("#6E6A6B")
```

Figure 19: CityEngine Web Scene model of the railings on the main entrance of the Student’s Residence building.

The creation of the railings is an example of a complex procedural modeling language. Attributes such as barDiameter are manipulated by the *t* and *s* operations. The *s* operation sets the size vector scope.s. The *t* stands for translation and the operation *s* is relative to the scope axes.

Basically the user has to learn the concepts such as the *t* and *s* operations in order to learn how to manipulate the bar shape for the railings element.

Another approach could have been made in this situation by creating the railings using manual shape creation tools.

2.4.3 Ágora Buildings

The Ágora is the main central square of the UJi campus. It is an open space in the center of the campus where social and cultural events take place. Around the Ágora there are many shops, bars and restaurants and galleries. In the buildings adjacent to the Ágora it is possible to find the Student Association and other university services.

Figure 20: CityEngine Web Scene of the Ágora buildings.

Next, are some samples of the CGA rule file for the Ágora buildings (Annex 3), more specifically for the back facade (see figure 20). Since some of the Ágora buildings have a half-circular shape, the footprint had a quite large number of vertices to give this format to the buildings. After running the clean-up shape tool to the footprint and assigning the extrusion operation, the back facade (West direction) had discontinued facades, identical to the ESTCE building (See figure 21).

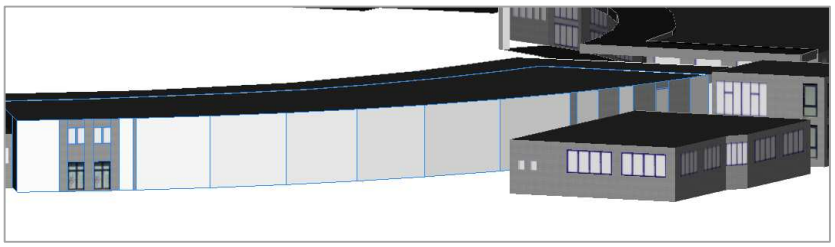


Figure 21: Discontinued facades in Ágora buildings in CityEngine.

```
1:          Footprint1 --> extrude (world.y, 7.50)
2:          comp (f) { world.north: north | world.south: Wall |
3:    |world.east: east(comp.index) | world.west: west (comp.index) |
4:          world.up: Roof }
```

Figure 22: CityEngine Web Scene of the Agora West facade 3D model.

To solve the problem the West facade had to be split using the comp index operation, resulting the shapes “A”, “L” and “windowFrame”.

```
1:    A --> split (x) {~0.5: Wall | ~0.8: SplitA |
2:    ~0.5: Wall}

3:    SplitA --> split (y) {~0: Wall | ~1: Window2 |~1:     Window2    |
~0.2: Wall}


15:   L -->
16:   split (x) {~0.3: Wall | ~0.8: SplitA | ~0.5: Wall | ~1: SplitL |
17:   ~0.5: Wall | ~1: SplitL | ~0.2: Wall}

18:   SplitL --> split (y) {~0: Wall | ~1.8: Door1 | 2: Wall | ~1:
19:   WindowFrame | ~0.5: Wall}

20:   WindowFrame --> split (x) {~1: Window2 | ~0.2: Wall | ~1:
21:   Window2}
```

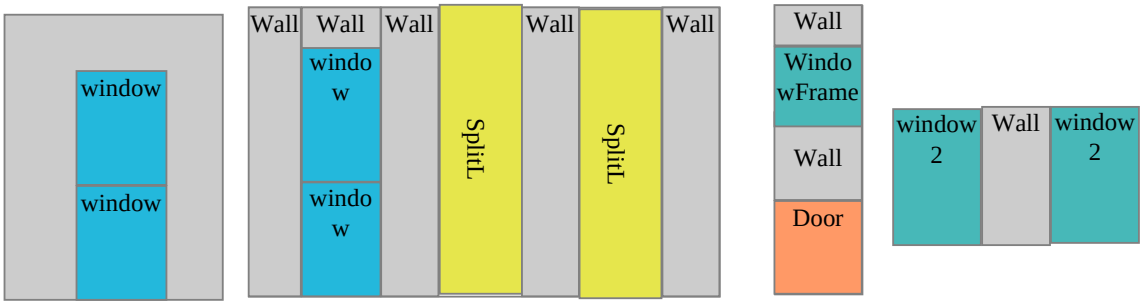


Figure 23: Basic facade design for the rules A, K and WindowFrame of the West facade in the Agora buildings.

From all the design of the Ágora this was the most complex facade. The Ágora building entire code is on the appendices (Annex 2) for further analysis.

2.4.4 The Workshops Building

The next building on my analysis is the Workshops ("Talleres") building. It is placed on the South side of the campus and it is a quite easy building to create in 3D. However, for this building it was decided to use a mix approach of both modelling methods. For the lateral buildings, which look like workshop rooms, the building texturing was accomplished by using the Static Texturing Tool (see section 2.6.2) and real photographs were taken in order to be applied in the facades. The main and central part of the building was created by using procedural modelling language. On annex 3 is the building complete code for further analysis.

Figure 24: CityEngine Web Scene of the 3D Workshops building model.

In the section "texturing the model" the texturing techniques will be explained more thoroughly, as well as, the tools CityEngine provide for the manipulation and editing of photographs.

2.5 Manual Modeling

This section details an introductory example of modeling without CGA shape grammar, i.e. using the polygonal modeling tools. Actually, the first part of this project was learning how to use these tools, mainly because they are very easy to comprehend and learn about CityEngine's dynamic.

The polygonal modeling tools allow the user to create rectangular or polygons shapes, modifying their shape, size, height, orientation. It is possible to add windows, doors by only drawing them and applying texture.

With these tools, CityEngine allows the user to quickly design and built a building with textures associated. For this project in particular, it took more time, since it had to look as close as possible to the real building. However, it can be very amusing if there are no "rules to follow", to build whatever desired. The following figure, extracted from CityEngine Help Guide, shows the tools used for manual modeling.

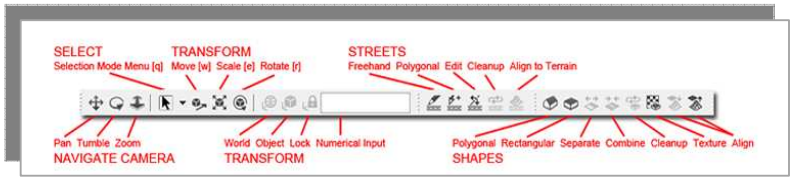


Figure 25: Creating and Editing shapes manually toolbar in CityEngine (CityEngine Help, 2011).

The select tool provides selection of shapes, vertices and edges. The shapes can be transformed using the Move, Scale and Rotate tools. This set of tools in particular was very useful when importing static models (Wavefront OBJ. files) into the scene. (See section 2.7)

The polygon shape creation tool is the main set for the manual modeling. It has an extremely useful snapping property and includes features such as: 90 degree angles, parallel lines, extensions of lines and line midpoints. All snapping features are automatically intersected to form combined snapping results. While moving the mouse, an orange dashed line is shown whenever snapping to such a feature occurs.

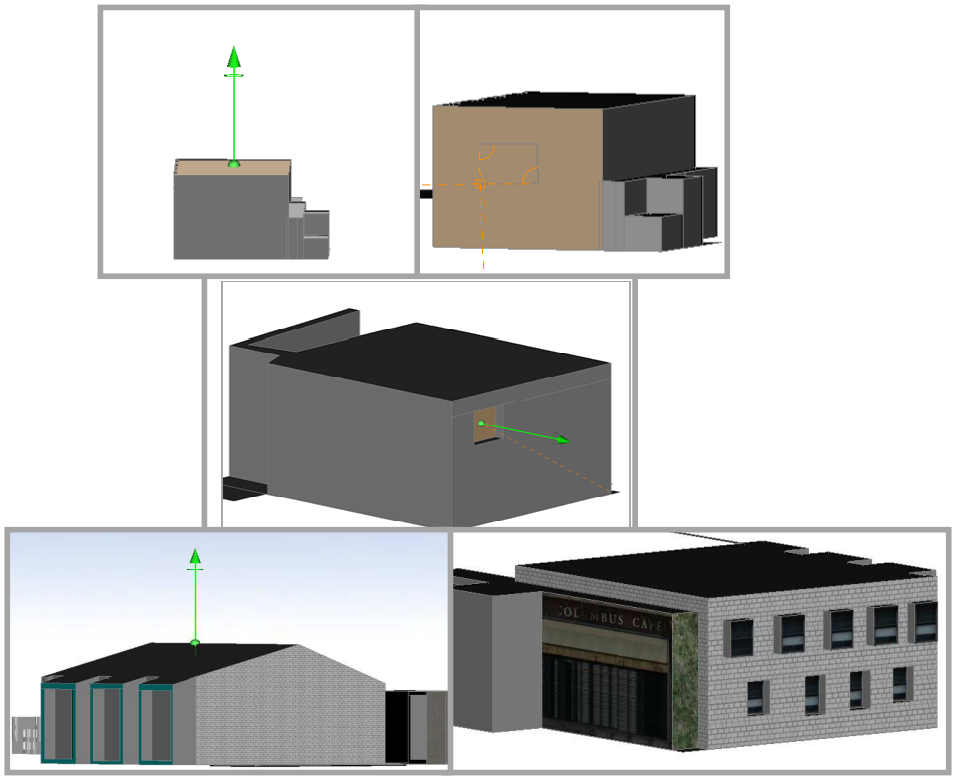


Figure 26: Examples created on the fly to show the usage of the polygon shape modeling tools in the ViscaUJi CityEngine scene.

Another important component of this section is the shape manipulation operations. These operations work directly on the components of shapes: Polygons (faces), vertices and edges. The *Separate Faces* operation creates an individual shape for every face. All new shapes are put in the layer of the original shape, which means that, it makes possible to apply CGA rule files. So far, the shapes created under this tools are classified as *faces* (of the polygons), when separated they became shapes. *Combine Shapes* creates one shape containing all components of the selected shapes.

The CleanUp Shape tool cleans the geometry of selected shapes or/and faces. It is a very useful operation especially after working with the previously explained tools. This tool will merge vertices, if the distance between two vertices is lower than the threshold; removes coplanar edges; removes multiple vertices on one straight line; removes double faces and Zero faces (with zero size); intersect edges; polygons that overlap on the same plane are split along all edges into multiple non-overlapping

polygons; and it is distance and angle tolerance. It always best to perform a CleanUp operation before applying textures.

The following section talks about two university buildings created exclusively with the polygonal modeling tools.

2.5.1 The Sports Building

The University Jaume I offer many sports activities within the campus. Besides having a sports pavilion, it offers outdoor areas, such as, football fields, tennis courts, basketball courts, and many more.

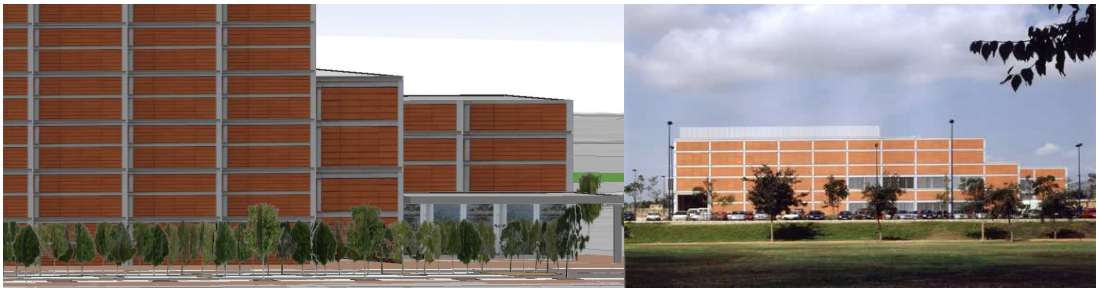


Figure 27: The image on the left is the CityEngine Web Scene of the 3D model of the entrance facade of the Sports building. On the right, a photograph from the Sports building. (Arqa.com. Pabellón polideportivo de la Universidad Jaume I de Castellón. November 2004. January 2013. *http://arqa.com/arquitectura/internacional/pabellon-polideportivo-de-la-universidad-jaume-i-de-castellon.html*)

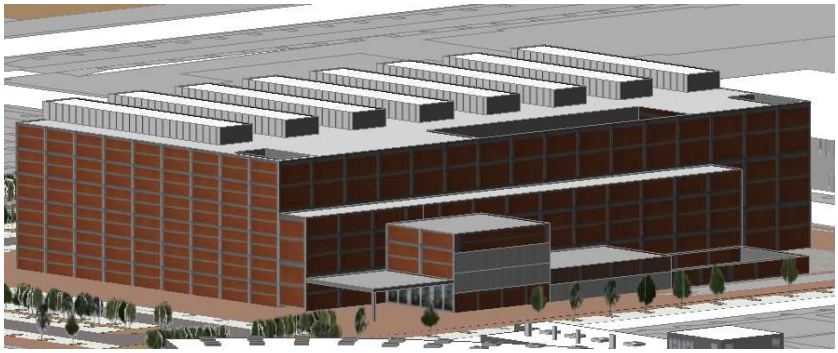


Figure 28: CityEngine Web Scene 3D Sports Building model.

The creation of the 3D building was exclusively by using the polygonal shape creation tools and the static texturing tool for applying the textures. The building model is not entirely accurate to what it looks like in reality. However, for the purpose of demonstrating the abilities of such tools it is satisfactory and sufficient.

2.5.2 Paranimfo/Auditorium Building

Uji's auditorium is a multi-purpose building designed to host academic events and performing arts. It has three floors, which includes a theatre, conference room, an outdoor terrace and various social sites.

The auditorium is a unique, attractive and modern infrastructure that serves both university population as well as, and the population of Castellón.

In addition, it provides a regular schedule of exhibitions, music concerts, film and performing arts during the academic year.

Figure 29: On top a photograph of the Auditorium (Castellon Convention Bureau - Turismo y negocios en Castellon. 2010. January 2013. http://www.castelloncongresos.com/web/index.php?option=com_onestabliments&task=listTipo&id=21&Itemid=33). And below, CityEngine Web Scene from the Auditorium building.

2.6 Texturing the model

Texturing the buildings is the final part of the 3D model creation and design process and is considered to be the most important technique in geovisualization in order to make geographic data visible.

For this project, two types of textures were used: digital textures and photographs. Digital textures were created previously to this study using Autodesk 3ds Max.

Textures for 3D models depend heavily upon the original photographs from which they are derived. Such photographs should to be taken in a perspectiveless manner. Perspectiveless means that the photograph taken has to be fully perpendicular to the subject. For efficient modeling, textures should be perspectiveless when we apply them to a model.

During this study, many photographs were taken of the university buildings. This task it was sometimes difficult to achieve. Most of the building facades were partially blocked by trees and cars, making harder the task of taking the photographs as straight as possible. Mid morning sun and shadows were sometimes a problem. Other inconvenient was the frequent reflection of people and other elements on the photographs due to reflective glass windows and doors. A high degree of scene detail and complexity can be achieved through the use of detailed textures on the buildings. With CityEngine, pictures of actual buildings are projected onto the surfaces of the building geometry. This method reproduces the most detailed facade.

A high-resolution, photo-realistic 3D environment allows university planners to see how a proposed building would interact with the existing environment, ensuring that the size, scale, and style of a proposed building are harmonious with the existing built environment. (Esri Smart Facilities, 2011)

2.6.1 Crop Image Tool

The Crop Image Tool is one of City Engine's tools was most used throughout the project. This tool has the wonderful ability to allow to crop the photographs taken, giving them the right depth and orientation. In earlier versions, the user had to be very careful how to take the picture of a real facade. For instance, the user had to be aware of certain rules such us taking it from the ground perspective otherwise the photograph and thus, the facade would look distorted.

Overall, it is an effective tool for the preparation of facade textures from ground based facade images; and the perspective correction are done in one step.

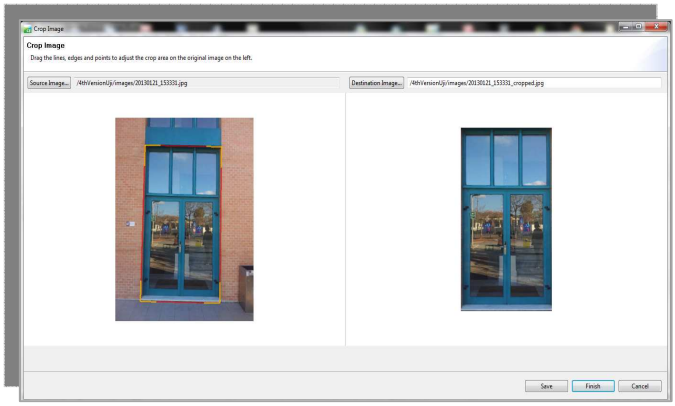


Figure 30: CityEngine's Crop Image tool. On the left side a photograph as input and on the right the result output.

2.6.2 Static Texturing Tool

The Static Texturing tool is a very simple and intuitive interface to apply textures, such as photographs or digital textures to the facades or faces of the shapes. For the exact texture mapping, several modes are available.

From the Navigator menu it possible to have access to all the images and after the selection of one, it is possible to rotate the image and flip it vertically or horizontally, and the most important definitions are under the “Textures Coordinates Mapping” menu. Four modes are possible to manipulate in order to get the perfect display of the image on the face/facade.

This was a very useful tool throughout the project, when modeling manually. It is intuitive and elementary.

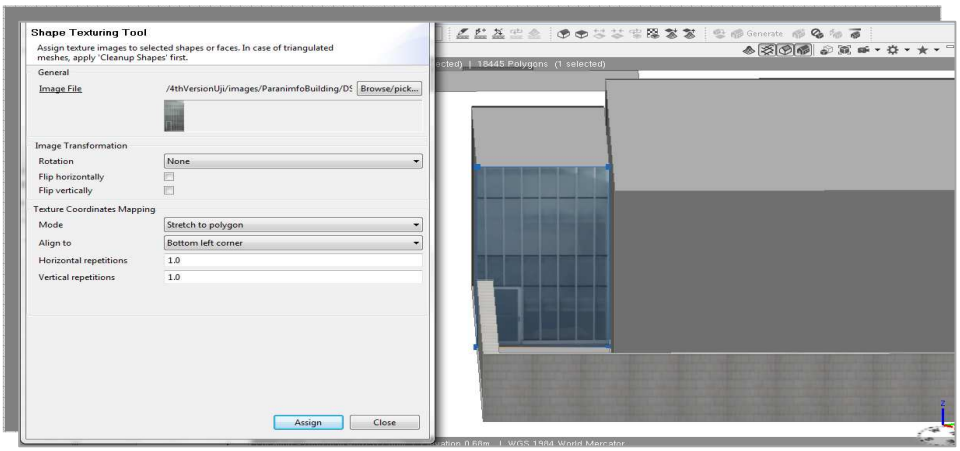


Figure 31: Use of City Engine’s Shape Texturing Tool in the Auditorium Building.

This chapter would not be complete without mentioning the Facade Wizard. Although it was not used within this project, it is a very interesting and useful tool for the textures practical application and display.

The singularity of this interactive tool is in the output. The Facade Wizard is somehow similar to the Crop Tool, with the addition that after cropping the image, the output is a CGA. Rule file that can be imported into a rule file and generate the facade.

2.7 Model Export and Integration

This project, as it was mentioned in the beginning, was divided into two parts: the street network and the buildings creation. The union of both models caused some difficulty. So far, the need for a more powerful machine wasn't an issue, till the moment came to join both 3D data. A part from these issues, the model export and subsequently, its publication online has brought some difficulties.

When the 3D scene is finalized, it can be exported as CityEngine Web Scene so it can be visualised in CityEngine Web Viewer, a web application for viewing 3D city scenes and other 3D scenes in a browser. It is based on WebGL technology which allows you to view 3D content in web browsers without installing additional plug-ins (ArcGIS Resources, 2013).

The user interacts with 3D city scenes by navigating in the scene by panning and zooming and changing perspective, select specific layers, swipe the scene to reveal different proposals and scenarios; and search scene content for features, attributes, and metadata.

So far, some major problems have occurred when trying to export the final scene of ViscaUJi as CityEngine Web Scene, more specifically, CityEngine shuts down before it can export the scene.

Apart from the Web Scene viewer, CityEngine's model export offers other file format options, such as: KML, Collada, Autodesk, Autodesk 3DS, Wavefront OBJ., ESRI File Geodatabase, among others. The most wanted format is the Esri File Geodatabase format so it can be loaded into ArcScene or ArcGlobe for further data analysis. City Engine’s primary strength is in 3D content creation. Most other 3D GIS tasks, such as visualizing large numbers of 3D GIS features, running 3D analysis, and maintaining 3D databases, are best performed using the ArcGIS 3D Analyst extension tools. (Esri CityEngine, 2012)

The data created in CityEngine is exported as file Geodatabase layer and added into ArcScene/ArcGlobe. The attribute table only contains the ObjectID and Shape fields, and no other information. And that happens bwhen CityEngine rebuilds the data in the Multipatch format. Multipatch is a geometry used as a boundary

representation for 3D objects in ArcGis and can be made up of a collection of triangle strips, triangle fans and/or triangles, circles and arcs. Multipatch is a 3D geometry used to represent the outer surface, or shell, of features that occupy a discrete area or volume in three-dimensional space. Multipatches comprise 3D rings and triangles that are used in combination to model a three-dimensional shell. Multipatches can be used to represent simple objects such as spheres and cubes or complex objects such as isosurfaces, buildings, and trees. (Esri White Paper, 2008)

The data in multipatch format in ArcScene allows, for instance, adding fields (attributes), move the objects/shapes, but not editing.

This issue needs further development, especially to understand how far the user can manipulate the data in order to query it and realize spatial analysis.

Another issue worth mention is the OBJ. buildings. Before this project begins, there were already 3D university buildings created in Autodesk 3D Studio Max. These buildings are supposed to be part of this project, since it is 3D data already created.

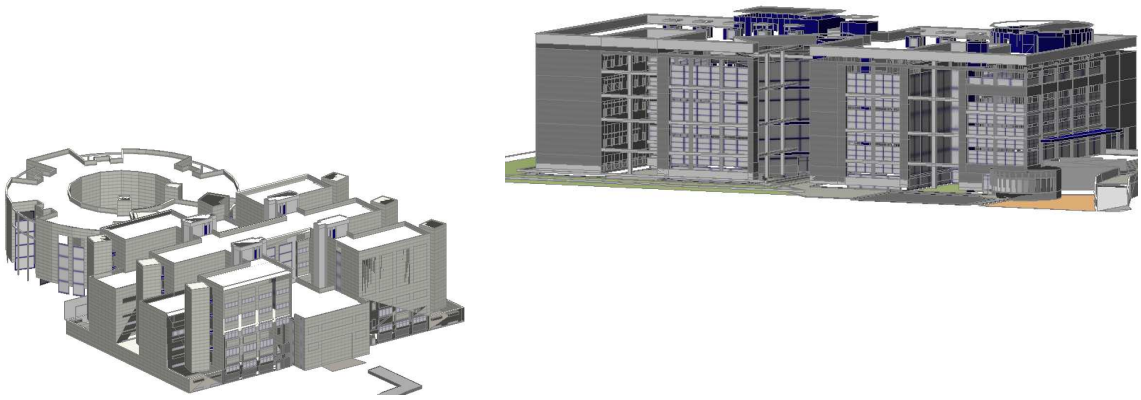


Figure 32: Autodesk 3D Studio Max university buildings. On the left, the Humanities Faculty and on the right, the Library. (Geotech, Uji Data)

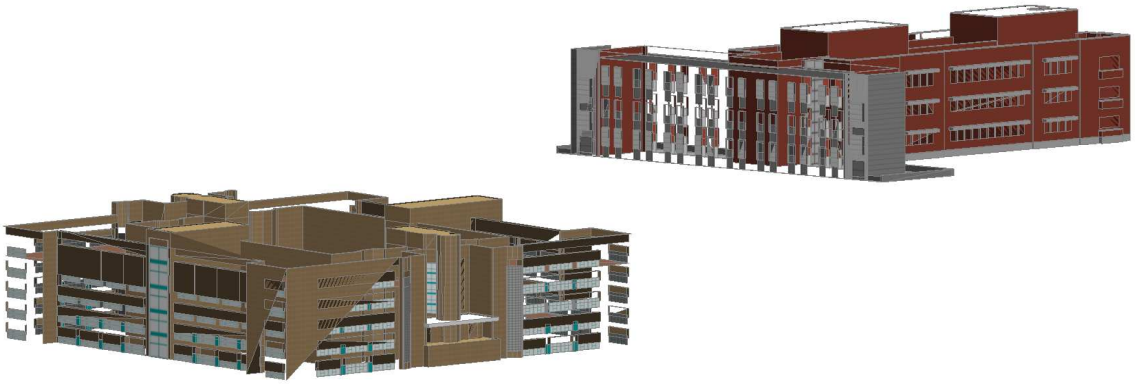


Figure 33: Autodesk 3D Studio Max university buildings: on the left image the Technology & Experimental Sciences building and on the right the Economics Faculty. (Geotech, Uji Data)

The only possible file format that when imported into CitEngine had “less” errors was Wavefront OBJ. Still, it presented major errors, for instance, missing walls, overlaying walls with windows, and so forth.

The buildings on the figure 33 are the perfect example of the problems mentioned above. To sum up, these buildings need a serious cleaning process and hopefully they will be fit to integrate the final model.

3 DISCUSSION

This chapter pretends to analyse two modeling approaches applied in this project and give some insight from the user perspective. This chapter is developed accordingly to my own singular experience with CityEngine and the ability to understand the quality of the software. Comparison analysis between other 3D modeling software is out of the scope of this study.

In table 1, the two modeling approaches are analysed and classified accordingly to some general properties of 3D geovisualisation: user interface; model; manipulation; navigation; visualisation; and time-consuming of the main tasks.

CityEngine's User Analysis	Manual Modeling	Procedural Modeling
User Interface	- Toolbar for creating and editing shapes manually; - Buttons shortcuts; - Mainly Usage of the mouse device.	- CGA Shape Grammar; - Using the CGA Editor window; - Mainly usage of the keyboard device.
Model	2D Geometry Extrusion using Polygonal or Rectangular Shape Creation tool	- 2D Geometry Extrusion - Operation Extrusion: extrude (*axisWorld*, *height*)
Manipulation	Track, Create, Move, Rotate, Scale and Zoom	Track and Zoom
Navigation	Orthogonal view, Perspective, Top, Front and Side	Orthogonal view, Perspective, Top, Front and Side
Visualization	Realistic Textures applied using shape texturing tool interface	Realistic textures applied with the CGA shape grammar
Time-taking Modeling	Short	Medium to Long
Time-taking Texturing	Short	Medium to Long
General level of complexity	Easy to Medium	Medium to Difficult

Table 1: CityEngine's user analysis applied to this study.

The user interface is the medium through which the information flows between the system and the user; it consists of a combination of graphics and text, a representation in a monitor and same manipulation through interaction devices, like a keyboard and a mouse.

Interaction is a somewhat generic term comprising the process of a human communicating with the computer. Interaction and navigation are thus not exactly separable but for the following considerations interaction is defined to be the process of interaction with the data and display aiming at gaining insight.

Navigation is an important part of 3D geovisualization as it allows the user to overcome occlusion (e.g. making hidden objects visible through a change of the viewpoint) or to look at the information from a different angle (a form of re-expression) (Nielsen, 2007).

Firstly, regarding the use of procedural modeling language, it revealed to be somehow easy to pick-up and efficient. All the 3D design and modeling is made through the CGA shape grammar and using the CGA editor view in the program.

The main advantage over the manual modeling is the flexibility that gives to the user. When creating a 3D model of a building, a street and/or street furniture, the user can always go back and modify parameters in the rules. Likewise, the same CGA rule can be assigned to many buildings, if in reality they have the same architectural style, for instance, some CityEngine examples for the cities of Paris or New York.

Perhaps for a user with few programming skills it can be a bit alarming. Definitely it can take a certain amount of time to understand how Computer Generated Architecture works and the shape grammar. However, CityEngine can be considered as user-friendly software, and when the user acquire the knowledge of procedural language, there are many things to create and design. It is a new world! And the best of it is that it is in 3D!

Finally, regarding the manual modelling, this method uses polygon shape creation/editing tools and it’s known to be more intuitive and faster to comprehend. Indeed, this method can be somewhat similar to other manual procedures used in other 3D softwares such as Google SketchUp.

The manual modeling main characteristic is the intuitive and simple set of tools that the user can and should use. It's less time-consuming, the opposite of the other method, it is faster and can generate beautiful 3D buildings, but not in a mass-production way. So it is less time-consuming if the user is working on minor dimension objects or working with details. To produce entire 3D urban cities manual modeling is definitely out of question.

While working with the CityEngine's set of manual tools, in particular the main disadvantages are: 1) there isn't a measuring tool, the only notion a user might have while drawing a building is when using the polygon shape creation it has a counter that is measuring while you are drawing; 2) there is no circle or arc creation tool, when designing urban landscapes elements such as columns are important.

In general, the main advantage of the manual modeling approach is the fact that isn't dynamic, as the procedural modeling language. For instance, after a 3D building is finalized, the user needs to change the measures of the windows, with CGA shape grammars that can easily be modified in the rule file and press to generate again. If using manual tools the user will need to draw again the object.

In summary both methods have their strengths and weaknesses. Nevertheless, procedural modeling language is the best within CityEngine environment to model 3D models. In the majority of the cases, the optimal approach is to mix both methods, for instance finishing details in a building using manual tools (in case the shape grammars become too complex or impossible to reproduce such detail).

4 CONCLUSION

The University Jaume I have made a major investment with the project Smart Campus. ViscaUJi not only models the existing built environment but also looks into the future; it has allowed the university to centralize campus maps, plans, and planning content. Further, it has improved data access for future development planning and review. Using Esri products such as City Engine as the foundation for a 3D campus designing helps a pioneer the usage of 3D GIS-based solutions.

The project outlined here and the resulting 3D university buildings will hopefully be used as a resource for 3D visualizations and navigation, as well as, a source of data – 3D data. 3D visualization and navigation of 3D maps provide a powerful way to explore the campus information by visualizing the data through different points of view.

From 2008 till nowadays, CityEngine has been growing and developing into 3D GIS program. Nonetheless, CityEngine still has a long way to go.

So, where does CityEngine stands in GIS world? Undoubtedly CityEngine's main power is to rapidly build accurate and visually compelling city models. However, that doesn't make CityEngine GIS software, but an average 3D model creator/designer. What makes CityEngine "GIS efficient" is allowing a GIS user to use its own GIS data.

The software allows to import and export attributed GIS data such as streets network, buildings footprints, or 3D buildings using the Esri file geodatabase or shapefile format. However, to perform further spatial analysis after working in CityEngine the user will have to export it and add into ArcGis 3D analyst set of tools.

Regarding the practical experience of this study, working with CityEngine was quite an exceptional and new experience. From the point of view of a Geographer, understanding and working with procedural modeling language was very challenging.

In the beginning the learning process was somehow slow, but in the end, the difficulties were overcame and now consider myself a competent user of CityEngine.

In conclusion, CityEngine is amazing 3D modelling software for geographers and professionals who work daily in Urban Planning departments and need sophisticated and reliable software to help planning and managing a city. Using software like CityEngine in Smart Cities or Smart Campus projects is a step forward into progress and development of the today's urban reality.

4.1 Future Work

Further work on this topic should focus on the following:

- Integration with other Smart Campus projects. Usage and linkage of the 3D data created in this project with the applications developed or to be developed in the future.
- Finish the designing and creation of the remaining university buildings.
- Indoor Mapping using the available CAD files for the buildings at Uji. Architectural drawings are essential to designing, narrating, and executing a construction project. Most drawings take the form of floor plans, which portray an orthographic top-down projection of each building level. Floor plans have various levels of detail, including the rooms, hallways, stairs and architectural

components. CAD files manage to cover the building's complete layout, which is sufficient to build a model for most applications. (Yin & Wonka & Razdan, 2013)

- Creating a Query tool with 3D visualization: 3D city information modeling exploration through 3D navigating and querying is particularly crucial since its purpose is to extract the relevant information in the available data. (Fredericque & Lapierr, 2010)
- In the end, while researching for the theoretical framework of this study, a considerable amount of literature was found regarding the topic 3D Geovisualisation. More specifically, a framework for evaluating the usefulness and appropriateness of 3D geovisualization. It would be very interesting to make a deeper and qualitative analysis of the work produced within this study to assess the data quality produced. The analysis would take into account, for instance, the concepts of evaluating usability and usefulness. Furthermore, a review of different parameters to help the purpose-based definition of tasks for the evaluation of usefulness. Generally, it would be interesting to look at non-technical aspects of this study.

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Annexes

Annex 1: CGA Rule File for the ESTCE Building.

```
File:    ESTCE.cga
Created: 5 Dec 2012 14:57:52 GMT
Author:  Sara Antunes


#ATTRIBUTES

attr tile_width = 3
attr windowwidth = 2
attr floorNumber = -1
attr floorheight = 3

#TEXTURES

MainTexture = "assets/facades_uji/ladrillo_caravista_det.png"
WindowTexture = "assets/facades_uji/VENHO_TI.jpg"
MidTileTextureRed = "assets/facades_uji/GRANATE MATE.jpg"
MidTileTexture = "assets/facades_uji/VERDE UJI.jpg"
Shape13WindowTexture = "assets/facades_uji/VENHOC_TI.jpg"
SideWindowTexture = "assets/facades_uji/VENHOC_TI_cropped.jpg"
LateralWindowTexture ="assets/facades_uji/VEN.jpg"
RoofTexture = "assets/facades_uji/flatroof5.png"
WestEntranceWindTexture = "assets/facades_uji/VENHO_TI_2.jpg"
UjiBlueTexture = "assets/facades_uji/MORADO UJI.jpg"
GreenTileTex = "assets/facades_uji/VERDE UJI.jpg"
DoorESTCE = "images/DoorESTCE.jpg"


#CODE FOR THE TWO TRIANGULAR-SHAPE BUILDINGS
@StartRule
Footprint1 --> extrude (world.y, 20)
comp (f) {object.front: EastFacade. | object.back: SouthFacade
(comp.index) | object.left:  SouthEastFacade1. | object.right:
WestFacade (comp.index)| object.top:  Roof}


#FOOTPRINT1 FACADES RULES

EastFacade. -->
split(y) { ~1:  Walltexture | ~1: wallSplit | ~1: Walltexture | ~1:
wallSplit| ~1: Walltexture | ~1: wallSplit| ~1: Walltexture | ~1:
wallSplit | ~1: Walltexture}

wallSplit -->
split(x) {~1: texture | ~1: window | 1: column | {  ~1: window } | 1:
column | ~1: window | 2: texture }

column -->
color ("#ff0000")

Walltexture -->
setupProjection(0, world.xy, 1.5, 1, 1.5)
```

```
setupProjection(1, world.xy, scope.sx, scope.sy)
texture(MainTexture)
tileUV(0, ~1, ~1)
projectUV(0)


SouthFacade(id) -->
      case id == 0:
      #color (1,0,0)
      SouthEastFacade1.
    case id == 1:
      #color (1,0,0)
      Walltexture
   case id == 11:
      #color (1,0,0)
      Shape11.
    case id == 12:
      #color (1,0,0)
      ShapeLateralWindow2.
    case id == 13:
      #color (1,0,0)
      Walltexture
        else:
      SouthFacadeComplete.


#SHAPES THAT RESULTED FROM THE SPLIT.INDEX OPERATION

SouthEastFacade1. --> split (x) { ~0.5: WallTexture | ~1: windowSplit |
~0.7: WallTexture }

window -->
      setupProjection(0,scope.xy,scope.sx,scope.sy)
      texture(WindowTexture)
      projectUV(0)


windowSplit -->
split (y) {~1: WallDoor | ~1: Sidewindow | ~1: Sidewindow |
~1:Sidewindow | ~0.5: WallTexture }



#SHAPE NUMBER ELEVEN FROM THE SPLIT INDEX HAS A DIFFERENT RULE WAS
APPLIED TO SOLVE THE BRICKS DISTORTION
Shape11. -->
      setupProjection(0, world.xy, 1, 1, 1)
      setupProjection(1, world.xy, scope.sx, scope.sy)
      texture(MainTexture)
      tileUV(0, ~1, ~1)
      split(x) {~floorheight : Floor }



ShapeLateralWindow2. -->
split (x) {~2: Walltexture| ~1.5: LateralwindowSplit | ~0: Walltexture}
```

```
LateralwindowSplit -->
split (y) { ~1: Lateralwindow | ~1: Lateralwindow | ~1: Lateralwindow |
~1: Lateralwindow | ~1: Lateralwindow | ~0.5: Walltexture }

SouthFacadeComplete. --> split(x) {~floorheight: Floor }


Floor --> split(y) {~1.5: Walltexture|  {~5: Tile}* | ~1: Walltexture }


Tile--> split(y) {0.5: Walltexture | ~1: window| 0.5: Walltexture}



#LAST FACADE RULE
WestFacade (id) -->
            case id == 0 :
            #color (1,0,1)
            EastFacadeInverse.
            case id == 1 :
            #color (1,0,1)
            ShapeLateralWindow1.
            else :
            #color (1,0,1)
        ShapeLateralWindow1.


EastFacadeInverse. --> split(y) { ~1:  texture | ~1: wallSplitInverse |
~1: texture | ~1: wallSplitInverse| ~1: texture | ~1: wallSplitInverse|
~1: texture | ~1: wallSplitInverse | ~1: texture}

wallSplitInverse -->
split(x) {~0.2: Walltexture | ~1: window | 1: columnYellow | {  ~1:
window } | 1: columnYellow | ~1: window | 10: Walltexture }

columnYellow --> color ("#ffb000")


ShapeLateralWindow1. -->
split(x) { ~0.5: Walltexture |  ~1.5: LateralwindowSplit | ~2:
Walltexture }



#ROOF RULE COMMON FOR ALL THE FACADES
Roof -->
      setupProjection(1, world.xy, scope.sx, scope.sy)
      texture (RoofTexture)
      tileUV(1, ~1, ~1)
      projectUV(0)



#SECOND RULE FOR THE TRIANGULAR-SHAPE BUILDING
Footprint2 --> extrude (world.y, 20)
comp (f) {object.front: NorthEastFacade (comp.index)| object.back:
EastFacadeInverse.  | object.left: NorthEastFacadeb (comp.index) |
object.right:  EastFacade. | object.top:  Roof }
```

```
NorthEastFacade (id) -->
      case id == 0 :
      color (1,0,0)
      SouthEastFacade1.
   case id == 1 :
      #color (1,0,0)
      texture
    case id == 6:
      Shape11.
    case id == 7 :
      #color (1,0,0)
      ShapeLateralWindow2.
    else :
        SouthFacadeComplete.



SouthEastFacade1.  -->
split (x) { ~0.5: Walltexture | ~1: windowSplit | ~0.7: Walltexture }


Sidewindow -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture(SideWindowTexture)
projectUV(0)


WallDoor -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture (DoorESTCE)
projectUV (0) projectUV (0)


Lateralwindow -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture(LateralWindowTexture)
projectUV(0)


NorthEastFacadeb (id) -->
      case id == 0:
      #color (1,0,0)
      ShapeLateralWindow2.
    case id == 1:
      #color (1,0,0)
      SouthEastFacade1.
      case id == 2:
      #color (1,0,0)
      Shape11.
   case id == 8 :
      #color (1,0,0)
      texture
    else:
       SouthFacadeComplete.
```

```
#FOOTPRINT 3
#TWO CENTRAL BLOCKS AND CIRCLE
Footprint3 --> extrude (world.y, 24)
comp (f) {world.south : LateralSide | world.west : WestEntrance |
world.east: EastEntrance | world.north: LateralSide | world.up: Roof }


@Location(1120,1493)
LateralSide -->
            setupProjection(1, world.xy, scope.sx, scope.sy)
            texture (MainTexture)
            projectUV(0)


WestEntrance -->
split(x) { ~0.3: Walltexture|  ~1: TileWestEntrance | ~0.3: Walltexture
}

TileWestEntrance -->
split(y) { ~0.5: Walltexture | ~1: windowWestEntrance | ~1: Walltexture
| ~1: windowWestEntrance | ~1: Walltexture | ~1: windowWestEntrance |
~1: Walltexture | ~1: windowWestEntrance | ~1: Walltexture | ~0.2:
Walltexture }

windowWestEntrance -->
               setupProjection(0,scope.xy,scope.sx,scope.sy)
               texture(WestEntranceWindTexture)
               projectUV(0)

EastEntrance --> split(x) {~1: Walltexture | ~2: TileEastEntrance | ~1:
Walltexture }


TileEastEntrance --> split(y) {~2.5: t | ~1: windowWestEntrance | ~1:
Walltexture| ~1: windowWestEntrance | ~1: Walltexture | ~1:
windowWestEntrance | ~2: Walltexture }



#RULE FOR THE BLOCK IN THE CENTER
Footprint3b --> extrude (world.y, 24)
comp (f) {world.south : Walltexture | world.west : Shape00. |
world.east: Entrance2 (comp.index) | world.north: LateralSide |
world.up: Roof}


Entrance2 (id) -->
      case id == 0:
      #color (1,0,0)
      Shape00.
      case id == 1:
      color ("#0000ff")
      TheWall.    #UJI BLUE WALL
      case id == 2:
      #color (1,0,0)
      Shape00.
else:
    LateralSide
```

```
Shape00. --> split (x) { 1: Walltexture |  ~1: TileSplit | 1:
Walltexture }

TileSplit-->
      split(y) { ~0.4 : WallDoor | ~0.8: Sidewindow00| ~0.1: GreenTile
| ~0.5: Sidewindow00 |~0.2: GreenTile | ~0.1: Walltexture }

GreenTile -->
setupProjection(1,scope.xy,scope.sx,scope.sy)
projectUV (0)
texture (GreenTileTex)


Sidewindow00 -->
               setupProjection(0,scope.xy,scope.sx,scope.sy)
               texture(SideWindowTexture)
               projectUV(1) projectUV(0)



Footprint3circle -->
extrude (world.y, 24)
setupProjection(1, world.xy, scope.sx, scope.sy)
texture (MainTexture)
projectUV(0)
```

Annex 2: CGA Rule File for the Students Residence Building

```
 * File:   Residence.cga
 * Created: 25 Nov 2012 17:42:09 GMT
 * Author:  Sara Antunes


attr floorheight = 3
attr windowwidth = 2
attr groundfloorheight = 3
attr floornumber = 4
attr tile_width = 1
attr tile_widthanother = 3

const barDiameter = 0.1
const cyl_v = "general/primitives/cylinder.vert.8.notop.tex.obj"
const cyl_h = "general/primitives/cylinder.hor.8.notop.tex.obj"


#TEXTURES
windowResidence = "images/DSC02187_cropped.JPG"
wallTexture = "assets/facades_uji/ladrillo_caravista_det.png"
wallcolor = "assets/facades_uji/GRANATE MATE.jpg"
GlassDoor2 = "images/GlassDoor2_cropped.png"


@StartRule
Footprint1 --> extrude (world.y, 24)
comp(f) {world.south :  SouthFacade (comp.index)  | world.west :   S |
world.east:  Wall2 | world.north:  NorthFacade | world.up: color
("#777") R }


SouthFacade (id) -->
case id == 0 :
BackWall
case id == 1 :
Wall2
else:
MainFacade


NorthFacade -->
split(y) { ~1.5 : Wall2 | ~0.5: wallSplitNorth| ~1 : Wall2 | ~0.5 :
wallSplitNorth| ~1 : Wall2 | ~0.5: wallSplitNorth | ~1: Wall2 | ~0.5:
wallSplitNorth | ~0.5: Wall2}


wallSplitNorth -->
split(x) { ~1: windowTex | ~ 1 : windowTex |  ~1 : windowTex | ~1:
windowTex | ~1: windowTex | ~1: windowTex | ~1: windowTex | ~1:
windowTex | ~1: windowTex | ~1: windowTex | ~1: windowTex  | ~1:
windowTex }


#EAST MAIN BLOCK WITH FLOORS SPLITED ACCORDING TO COLORS!
Footprint1aa --> extrude(world.y, 24)
```

```
split (y) { ~1 :  FirstFloor| ~1: SecondFloor | ~1: ThirdFloor | ~1:
FourthFloor | 2: FifthFloor }

FirstFloor -->
split (z) {~1: NIL | ~1: NIL | ~1: NIL }

SecondFloor -->
split(z) { ~1 : pinkWindowSegment | ~1: yellowWindowSegment | ~1:
yellowWindowSegment }

ThirdFloor -->
split(z) { ~1 : yellowWindowSegment | ~1: yellowWindowSegment | ~1:
pinkWindowSegment }

FourthFloor -->
split(z) { ~1 : yellowWindowSegment | ~1: pinkWindowSegment | ~1:
pinkWindowSegment }

FifthFloor -->
split (z) {~1: yellowRoofSegment | ~1: yellowRoofSegment | ~1:
pinkRoofSegment }


pinkWindowSegment -->
split(y) {~1 : color("#ff9999") X | 2 : windowTex}

yellowWindowSegment -->
split(y) {~1 : color("#ffff66") X | 2 : windowTex}

yellowRoofSegment --> comp (f){top : color ("#b7b7b7") X | side :
color("#ffff66") X}

pinkRoofSegment --> comp (f) {top : color ("#b7b7b7") X | side :
color("#ff9999") X}

@Location(567,906)
Footrprint1bb --> extrude (world.y, 5.5)
comp(f) {
      0: color("#b7b7b7") X |  //roof
      1: color("#b7b7b7") X |  //botom
      3: color("#ff6699") X    //side facade
      }


windowTex -->
texture(windowResidence)
projectUV (0)
tileUV(0,0,0)


Column --> extrude (world.y, 6)
           color ("#ffffff")



//MAIN BLOCK WEST DIRECTION
Footprint2 --> extrude (world.y, 24)
```

```
comp (f) {world.south : Wall2 | world.west : SideFacade | world.east:
Wall2 | world.north: MainEntrance2 | world.up: color ("#777") R }


MainEntrance2 --> split (x) {~0: Coral2 | ~1.5: CoralSplit | ~1: Coral2
}

CoralSplit --> split (y) { ~0: Coral2 | ~2: DoorGlassEnt | ~0.8: Coral2
| ~1.5: DoorGlassEnt | ~0.8: Coral2 | ~1.8: DoorGlassEnt | ~0.8: Coral2
| ~1.5: DoorGlassEnt | ~1: Coral2 }


#MAIN FACADE WITH UNIQUE COLOR

MainFacade -->
texture (wallcolor)
projectUV(0) projectUV(1)

@Location(977,525)
SideFacade -->
split(y) { ~2 : GroundFloor | ~0.5: wallSplit| ~1 : Wall2 | ~0.5:
wallSplit| ~1: Wall2 | ~0.5: wallSplit | ~0.5: Wall2}

wallSplit -->
split(x) { 2 : Wall2 | ~ 1 : windowTex |  ~1 : windowTex | ~1:
windowTex | ~1: windowTex | ~1: windowTex | ~1: windowTex | ~1:
windowTex | ~1: windowTex | 2 : Wall2 }


Wall2 -->
texture (wallTexture)
projectUV(1) projectUV(0)


GroundFloor -->
split (y) { ~4: F | ~1.5: Wall2 }

F --> split (x) {12: C| 5: Coral2 | 12: NIL | 32: Wall2 }

C --> split (y) {~3 : Coral2 | ~1: windowTex }


BackWall -->
texture (wallTexture)
projectUV(1) projectUV(0)
color("#ff9999")


DoorGlassEnt -->
texture (GlassDoor2)
projectUV(0)
tileUV(0,~7,0)


#FOOTPRINT 3
#ENTRANCE BUILDING WITH RAILING
Footprint3 --> extrude (world.y, 30)
comp (f) { side: Coral2 | world.up: R }
```

```
Coral2 -->
color ("#E55B3C")


MainEntrance --> extrude (world.y, 6.1)
comp (f) {world.north: split(y) { ~1: Railing | ~1: NIL } | world.west:
NIL  | world.up: Extra }

Extra -->
s('1, '1, 0.3)
i("builtin:cube")

Railing -->
      [t(0,scope.sy-barDiameter/1,0) HBar ]
      set(trim.vertical, false)
      split(x){ 3 :  VBar }*


VBar --> s(barDiameter,'0,barDiameter) t(0,0,-barDiameter) i(cyl_v)
color("#6E6A6B")

HBar --> s('1,barDiameter,barDiameter) t(0,0,-barDiameter) i(cyl_h)
color("#6E6A6B")



@Location(1094,183)
//SideFacade
S-->
      setupProjection(0, world.xy, 1.5, 1, 1)
      setupProjection(2, world.xy, scope.sx, scope.sy)


@Location(904,328)
R -->
      setupProjection(1, world.xy, scope.sx, scope.sy)
      projectUV(0)
```

Annex 3: CGA rule file for the Workshops building

```
 * File:    Talleres.cga
 * Created: 23 Nov 2012 12:27:26 GMT
 * Author:  Sara Antunes


#ATTRIBUTES
attr windowwidth =0
@Location(-442,437)
attr floorheight = 2

#TEXTURES
walltexture = "assets/facades_uji/ladrillo_caravista_det.png"
WindowTexture = "assets/facades_uji/VEN.jpg"
UjiWall = "assets/facades_uji/MORADO UJI.jpg"
Window2 = "assets/facades_uji/TallaresWindow2.png"
TallaresBackDoor="images/WorkShopsBuilding/TallaresBackDoor_cropped.JPG
BackWindow ="images/WorkShopsBuilding/TallaresWindow.JPG"
MainDoor = "images/WorkShopsBuilding/DoorTalleres.jpg"


#TRIANGULAR-SHAPE BUILDINGS
@StartRule
Footprint2 --> extrude (world.y, 5)
comp(f) {world.south: South | world.west: SouthWest | world.east:
NorthEast | world.north: North (comp.index) | world.up: color
("#c0c0c0") Roof }


South -->
split (x) { 3: Wall |  ~2: Tile2 | ~2: Wall }

Tile2--> split(y) {~0.1: Wall | ~1: window2 | 1: Wall}

SouthWest -->
split (x) { 4: Wall |  ~4: Tile2 | ~3: Wall }


NorthEast -->
split (x) { ~1: Wall |  ~1: Tile | ~1: Tile | ~0: Wall }

Tile--> split(y) {~0: Wall | ~2: window | ~2: window | ~1: Wall}

NorthWest -->
split (x) { 0: Wall | ~1: Tile | ~1: Tile | ~1: Wall }

North (id) -->
            case id == 0:
            #color (0,0,1)
            South
            case id == 1:
            #color (0,0,1)
            NorthWest
            else:
            South
```

```
#MAIN TEXTURE FOR THE WALL – LIGHT BROWN BRICKS
Wall -->
setupProjection(1, world.xy, 1.5, 1, 1.5)
setupProjection(1, world.xy, scope.sx, scope.sy)
texture (walltexture)
projectUV(0) projectUV(0)
tileUV (0,1,1)

#TEXTURES FOR THE WINDOWS
window -->  setupProjection(0,scope.xy,scope.sx,scope.sy)
            texture(WindowTexture)
            projectUV(0)


window2 --> setupProjection (0,scope.xy,scope.sx,scope.sy)
            texture (Window2)
            projectUV (0)

window3 --> setupProjection (0,scope.xy,scope.sx,scope.sy)
            texture (BackWindow)
            projectUV (0)

#DOOR TEXTURES
EntranceDoor -->
setupProjection (0,scope.xy,scope.sx,scope.sy)
texture (MainDoor)
projectUV (0)

DoorTex -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture (TalleresBackDoor)
projectUV (0)


#MAIN BLOCKS IN THE CENTER WITH BLUE UJI WALL
Footprint4 --> extrude (world.y, 8)
comp (f) { world.north: A | side: Wall | world.up: Roof }

A --> split (y) {~0.5: MidTile | ~1.5: Wall | ~1.5:TileA | ~1.5: TileA
|~4: Wall}

TileA --> split (x) {~3: Wall | 1.5: window | 1.5: window | 1.5: window
| 0.2: MidTile | 1.5: window | 1.5: window | 1.5: window | ~2: Wall }

MidTile --> color ("#FFFFFF")


#ROOF RULE
Roof -->
      setupProjection(1, world.xy, scope.sx, scope.sy)
      projectUV(0)


Footprint4b --> extrude (world.y, 12)
comp(f) {world.south: SouthFacade  | world.west: S | world.east: S |
world.north: Main | world.up: Roof }
```

```
SouthFacade --> split (x) {~1: Wall | ~1: BackDoor| ~1: Wall}

BackDoor --> split (y) {~0.05: Wall | ~1.8: DoorTex | ~4: Wall}

Footprint4a--> extrude (world.y, 12)
comp(f) {world.south: SouthFacade2 | world.west: Wall | world.east:
Wall | world.north: NorthEast2 | world.up: R }

SouthFacade2 --> split (x) {~0: Wall | ~1: WindowSplit | ~1: Wall| ~1:
WindowSplit | ~0: Wall}

WindowSplit --> split (y) {~0.5: Wall | ~2.5: window3 | ~1.5: Wall |
~2.5: window3 | ~2: Wall}

NorthEast2 --> split (x) {~0: Wall |~1: VenSplit | ~1: DoorSplit | ~1:
VenSplit | ~1: DoorSplit |~1: VenSplit | ~1: DoorSplit | ~1: VenSplit |
~0: Wall}

DoorSplit --> split (y) {~0: Wall | ~1.5: EntranceDoor | ~1.5: window |
~1.5: window | ~2: Wall}

VenSplit --> split (y) {~0: Wall | ~1.5: window| ~1.5: window | ~1.5:
window | ~2: Wall}
```

Annex 4: CGA rule file for the Ágora buildings

```
* File:    Agora.cga
* Created: 16 Jan 2013 13:26:28 GMT
* Author:  Sara


#TEXTURES
WindowAgora = "assets/facades_uji/VENHO_AGORA.jpg"
WallTex = "assets/facades_uji/CARAVISTA_BLANCO.jpg"
SmallWindowAgora = "assets/facades_uji/VENHO_AZUL.jpg"
ShopDoor = "assets/facades_uji/shopdoor.png"
Azul = "assets/facades_uji/VEN_AZUL_GRANDE.jpg"
VenhoAgora = "assets/facades_uji/VENHO_AGORA_cropped.jpg"
PublicityDoor1 = "images/Agora/PublicityDoor1.jpg"
PublicityDoor2 = "images/Agora/PublicityDoor2.jpg"
RealWindow = "images/Agora/RealWindow.jpg"


@StartRule
Footprint1 --> extrude (world.y, 7.50)
comp (f) { world.north: north | world.south : Wall | world.east: east
(comp.index) | world.west: west (comp.index) | world.up: Roof }

Column -->
extrude (world.y, 7)


#LATERAL WALLS
north --> split (x) {~0.1: Wall | ~0.4: WallSplit | ~0.2: Wall |  ~0.4:
WallSplit | ~0.2: Wall |  ~0.4: WallSplit  | ~0.2: Wall | ~0.4:
WallSplit | ~0.2: Wall }

WallSplit --> split (y) {~0: Wall | ~0.4: Window2 | ~0.4: Window2 | ~0:
Wall }


#FRONT WALL TOWARDS AGORA SQUARE
east (id) -->
case id == 0:
#color (1,0,0)
east1
case id == 1:
#color (1,0,1)
east4
case id == 2:
#color (1,0,2)
east1
case id == 3:
#color (1,1,0)
east3
case id == 4:
#color (1,0,3)
east4
case id == 5:
```

```
east1
case id == 6:
#color (1,0,0)
east6
else:
Wall


east1 --> split (y) {0.2: Wall | ~3: FirstSplit | ~1: Wall}
FirstSplit --> split (x) {~1: Wall | ~4: Window | ~0.5: Wall}

east2 --> split (y) {0.2: Wall | ~3: SecondSplit | ~1: Wall }
SecondSplit --> split (x) {2: Wall | ~0.1: Window | 2: Wall | ~0.1:
Window | 4: Wall }

east3 --> split (y) {0.2: Wall | ~3: ThirdSplit | ~1: Wall }
ThirdSplit --> split (x) {0.5: Wall| ~0.3 : Window | 1: Wall | ~0.3:
Window | 0.5 : Wall }

east4 --> split (y) {0.2: Wall | ~3: FourthSplit | ~1: Wall }
FourthSplit --> split (x) { ~0.5: Wall | ~1: Window | ~0.5: Wall | ~1:
Window | ~0.5: Wall }

east6 --> split (y) {0.2: Wall | ~3: SixSplit | ~1: Wall }
SixSplit --> split (x) {~0.2: Wall | ~0.5: Window | ~0.5: Wall}


#BACKSIDE WALL
west (id) -->
case id == 0:
A
case id == 8:
K
case id == 9:
L
case id == 10:
A
else:
K


#SplitA ITS FOR THE TWO VERTICAL WINDOWS
A --> split (x) {~0.5: Wall | ~0.8: SplitA | ~0.5: Wall }
SplitA --> split (y) {~0: Wall | ~1: Window2 | ~1: Window2 | ~0.2: Wall
}

#SplitL IS FOR THE DOOR AND THE TWO HORIZONTAL SMALL WINDOWS
L -->
split (x) {~0.3: Wall | ~0.8: SplitA | ~0.5: Wall | ~1: SplitL |  ~0.5:
Wall | ~1: SplitL | ~0.2: Wall }
SplitL --> split (y) { ~0: Wall | ~1.8: Door1 | 2: Wall | ~1:
WindowFrame | ~0.5: Wall}


K -->
split (x) {~0.3: Wall | ~0.8: SplitA | ~0.5: Wall | ~1: SplitL |  ~0.5:
Wall | ~1: SplitL | ~0.2: Wall | ~0.8: SplitA }
```

```
WindowFrame --> split (x) {~1: Window2 | ~0.2: Wall | ~1: Window2 }

Door1 -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture (PublicityDoor1)
projectUV(0)

Door2 -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture (PublicityDoor2)
projectUV(0)

Window -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture(WindowAgora)
projectUV(0)

Window2 -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture(SmallWindowAgora)
projectUV(0)

Window3 -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture(Azul)
projectUV(0)

Window4 -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture(VenhoAgora)
projectUV(0)

Window5 -->
setupProjection(0,scope.xy,scope.sx,scope.sy)
texture(RealWindow)
projectUV(0)


Wall -->
setupProjection(1,scope.xy,scope.sx,scope.sy)
texture(WallTex)
tileUV(1,~1,~1)
projectUV(0) projectUV (1)


Footprint2 -->
t(0,7,0)
extrude (world.y, 1)


#LITTLE HOUSES NEXT TO THE MAIN BUILDINGS
Footprint3 --> extrude (world.y, 6)
comp (f) { world.north : Wall | world.south : Wall | world.west : Wall
| world.east : BackWall | world.up : Roof }
```

```
BackWall --> split (x) {~0.3: Wall| ~0.5: Split | ~0.2: Wall | ~0.5:
Split | ~0.2: Wall | ~0.5: Split | ~0.2: Wall | ~0.5: Split | ~0.2:
Wall | ~0.5: Split | ~0.2: Wall}
Split --> split (y) {~0.7: Wall | ~0.5: Window2 | ~0.4: Wall}

WallDoor --> split (x) { ~0.3: Wall | ~0.8: SplitDoor | ~0.2: Wall |
~0.8: SplitDoor | ~0.5: Wall | ~0.8: SplitDoor | ~0.3: Wall }

SplitDoor --> split (y) { ~0: Wall | ~1: Door1 | ~0.3: Wall }


Footprint3b --> extrude (world.y, 6)
comp (f) { world.north: BackWall | world.south: BackWall | world.west:
Wall | world.east: Wall | world.up: Roof }


#AGORA INVERSE BUILDING
Footprint4 --> extrude (world.y, 8)
comp (f) { world.north: N (comp.index)| world.south : S (comp.index) |
world.east : E (comp.index) | world.west : W (comp.index) | world.up :
Roof }

E (id) -->
case id == 0:
#color (1,0,1)
east1
case id == 1:
#color (1,0,1)
Wall
else :
Wall


S (id) -->
case id == 0 :
#color (1,0,1)
north
case id == 1:
#color (1,0,1)
east7
case id == 2 :
#color (1,0,1)
east3
case id == 3 :
#color (1,0,1)
east7
case id == 4 :
#color (1,0,1)
east7
case id == 5 :
#color (1,0,1)
east4
case id == 6 :
#color (1,0,1)
east7
else :
Wall
```

```
east7 --> split (y) {0.2 : Wall | ~3: SevenSplit | ~1: Wall }
SevenSplit --> split (x) {~0.5: Wall | ~1: Window | ~0.5: Wall }

W (id) -->
case id == 0 :
#color (1,0,1)
DoubleA
case id == 1:
A
else :
Wall


#BACK WALL FOR THE OTHER AGORA BUILDING
N (id) -->
case id == 0 :
#color (1,0,2)
A
case id == 1 :
#color (1,0,2)
LInverse
case id == 2 :
#color (1,0,2)
K
case id == 8 :
#color (1,0,1)
SimpleK

else :
K

DoubleA --> split (x) {~0.5: Wall | ~0.3: DoubleSplitA | ~0.5: Wall }
DoubleSplitA --> split (y) {~0: Wall | ~1: Window2 | ~1: Window2 |
~0.2: Wall }

LInverse -->
split (x) {~0: Wall | ~0.5: Wall | ~1: SplitLInverse |  ~0.5: Wall |
~1: SplitLInverse | ~0.5 : Wall | ~0.8: SplitA | ~0.2: Wall }


SplitLInverse -->
split (y) { ~0: Wall | ~1.8: Door2 | 2: Wall | ~1: WindowFrame | ~0.5:
Wall}

SimpleK -->
split (x) { ~0.1 : Wall | ~0.3: SplitL | ~0.3: Wall | ~0.2: SplitA }


#BUILDINGS BEHIND
Footprint5 --> extrude (world.y, 10)
comp (f) {world.south: southSouth | world.west : southSouth |
world.east: eastEast  | world.north: northNorth |world.up : Roof }

Footprint5B --> extrude (world.y, 10)
comp (f) {world.south: eastEast | world.west: southSouth | world.east:
northNorth  | world.north: southSouth |world.up : Roof }
```

```
southSouth --> split (x) { ~0.1: Wall | ~0.2: SouthSplit | ~1: Wall |
~0.2: SouthSplit | ~0.1: Wall}
SouthSplit --> split (y) { ~0.2 : Wall | ~1: Window5 | ~0.2: Wall | ~1:
Window5| ~0.2: Wall }

eastEast --> split (x) {~0.1: Wall | ~0.2: SouthSplit | ~0.5: Wall |
~0.7: eastEastSplit | ~0.05: Wall }
eastEastSplit --> split (y) { ~0.1: Wall | ~0.4: Window3 | ~0.05: Wall
| ~0.4: Window3 | ~0.1: Wall }

northNorth --> split (x) {~0.05: Wall | ~0.7: eastEastSplit | ~0.5:
Wall | ~0.2: SouthSplit | ~0.1: Wall }

#RECTANGULAR SHAPE##AGORA RESTAURANT
Footprint6 --> extrude (world.y, 6)
comp (f) {world.north:  NORTH (comp.index) | world.south: Wall |
world.east: Entrance | world.west: ToHumanas | world.up : Roof }


NORTH (id) -->
case id  == 0 :
#color (1,0,1)
Logo
else:
LogoSplit


Logo --> split (x) {~0.3: Wall | ~0.2: SplitLogo | ~0.2: Wall| ~0.2:
SplitLogo | ~1: Wall | ~1.5: LogoSplit | ~0.3: Wall | ~1.5: LogoSplit |
~0.3: Wall}

LogoSplit --> split (y) {~1: Wall | ~1: Window4 | ~0.3: Wall }

SplitLogo--> split (y) { ~1.2: Wall | ~0.5: Window2 | ~1: Wall }

Entrance -->
split (x) { ~0.05: NIL | ~0.05: Wall | ~0.4: EntranceSplit | ~0.1: Wall
| ~0.4: EntranceSplit | ~0.3: Wall | ~0.1: SplitLogo | ~0.2: Wall |
~0.1 : SplitLogo | ~0.2: Wall | ~0.2: SplitDoor | ~0.2: Wall| ~0.1:
SplitLogo | ~0.2: Wall | ~0.1: SplitLogo | ~0.2: Wall}

EntranceSplit -->
split (y) {~0.05: Wall | ~0.3: Window4 | ~0.3: Window4 | ~0.1: Wall }

ToHumanas -->
split (x) { ~0.1: Wall | ~0.3: LogoSplit | ~0.1: Wall| ~0.3: LogoSplit
| ~0.1: Wall }


Footprint6B --> extrude (world.y, 6)
comp (f) {world.north:  Logo | world.south: OutDoor (comp.index) |
world.east: Agora1 (comp.index) | world.west: ToHumanas | world.up:
Roof }

OutDoor (id) -->
case id == 0 :
#color (1,2,0)
OutDoor_door
```

```
else :
Wall

OutDoor_door --> split(x) { ~0.3: Wall | ~0.4: SplitDoor | ~0.5: Wall }

Agora1 (id) -->
case id == 0 :
Agora1Split
else:
Wall

Agora1Split -->
split (x) { ~0.2: Wall | ~0.1: Window2Split | ~0.2: Wall| ~0.1:
Window2Split | ~0.2: Wall| ~0.1: Window2Split |~0.2: Wall| ~0.1:
Window2Split |~0.2: Wall| ~0.1: Window2Split | ~0.2: Wall }

Window2Split -->
split (y) {~0.05: Wall | ~0.5: Window2 | ~0.05: Wall }
```

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